Scenarios for a Low Carbon Belgium by 2050

Final report

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FOREWORD

We are committed to reducing our greenhouse gas emissions by 80 to 95% by 2050 relative to 1990. The route to a ‘low carbon society’ in 2050 will require substantial changes across a wide range of sectors and across many aspects of our lives. We have the opportunity to build that future.

Despite the difficulties in looking so far ahead, a successful low carbon transition requires a clear direction and early action. Investors and consumers require confidence to act, large building and infrastructure projects require long term planning, behaviours change gradually and new technology developments take time to reach commercial deployment. Time is shorter than it may seem and the pace of change has to increase drastically: significant decisions need to be taken in the coming decade, with some of them being clear ‘no regrets’.

We will need to achieve these emissions reductions and realise a just transition while at the same time securing energy supply and safeguarding, even enhancing, the competiveness of our industry. The challenge is not limited to Europe: countries all over the world are undertaking their low carbon transition and it is clear that the direction that other nations are taking will affect the opportunities and the risks for Belgium. In any case, we must grasp the benefits offered by the transition: enhanced innovation, green jobs, a reduced energy bill and lower health impacts through reduced air pollution, to name a few.

We welcome this study realised by Climact and VITO. It shows that various transition pathways allow us to reach the necessary reductions. The exercise is not about choosing a specific pathway towards 2050. But this study does give us an understanding of where the ‘good bet’ actions lie and of the timing of necessary decisions.

This analysis indicates that a low carbon society can even lead to lower total system costs, as additional investment expenditures will be compensated by reduced fuel expenses. Given the inherent uncertainty in predicting the likely price of fossil fuels over forty years, the low carbon transition reduces the exposure of our society to the risk of high fossil fuel prices.

Shifting towards a low carbon society will require the consent and participation of citizens. It will also require to innovate and to develop new thinking in, for instance, governance and financing structures.

We will continue to investigate the complementary questions raised by this work. A web interface is also provided that allows all stakeholders and citizens to access the study and to build their own low carbon scenarios.

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Federal Public Health, Food Chain Safety and Environment

Melchior Wathelet

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A. CONTEXT AND OBJECTIVES

Warming of the climate system is unequivocal, as demonstrated by observations of increases in global average temperatures, rising global average sea level and snow and ice melting.

The Intergovernmental Panel on Climate Change (IPCC) has analysed several global scenarios that explore alternative development pathways and cover a wide range of driving forces and resulting greenhouse gas (GHG) emissions. According to such analyses, the year 2050 is a milestone in the low carbon journey and negative GHG emissions will be required between 2050 and 2100 in order to keep a significant chance of remaining below a 2°C increase in global temperature.

The European Union (EU) has committed to reducing its GHG emissions by 80 to 95% in 2050 with respect to 1990. In order to give decision makers more certainty on the way such targets could be reached, the European Commission published in March 2011 a roadmap for Europe's transition towards a competitive low carbon economy in 2050. This roadmap has been complemented by specific roadmaps for the transport and the energy sector within the European Commission. Some industry sectors are also preparing their own industry roadmaps.

This study takes place in the context of the Cancún international agreements which, on the request of the EU, foresee that all industrialized countries should develop and implement low carbon development strategies (LCDS). EU Member States are therefore requested to develop and implement LCDS. Many initiatives have already taken place in several countries, such as the United Kingdom, Germany, Denmark, Sweden, Finland, France, The Netherlands and others.

Belgium must actively prepare the development of such a strategy. The ambition of the Federal government is that Belgium "join the group of European pioneers in the transition to new sustainable modes of economic production and consumption"[1] and its long term vision on sustainable development foresees, *inter alia*, a reduction of greenhouse gas emissions by at least 80-95% by 2050 with respect to 1990 on the Belgian territory. The Regions are currently working on visions, pathways and policies towards our mid- and long-term objectives. Many local initiatives are also taking place at the provincial and municipal levels.

A successful transition to a low carbon society must lead to a sustainable society that guarantees the respect of environmental resources, secures energy supply for consumers, ensures the competitiveness of businesses and recognizes the principle of shared but differentiated responsibility in the international context. The implementation of the transition will impact economic activity and employment: some sectors are expected to increase their activities, others will decline. An adequate, well prepared transition should ensure the competitiveness of businesses and allow the creation of quality jobs. To achieve this, it is essential to ensure a clear and stable policy framework that can support investment, technological innovation and training and development of workers' skills.

Consequently, the Climate Change Section of the federal administration for the Environment (FPS Health, Food Chain Safety and Environment) has commissioned a study for the elaboration of scenarios leading to 80 to 95% reductions of GHG emissions in Belgium in 2050 with respect to 1990, in the current context of the nuclear phase out. The study was carried out by CLIMACT and VITO.

[1] See Federal government agreement, December 2011.

Reaching such targets is very challenging. A significant increase in the yearly pace of GHG reduction is required over the coming decades to achieve an 80 to 95% GHG reduction as illustrated in Figure 1.

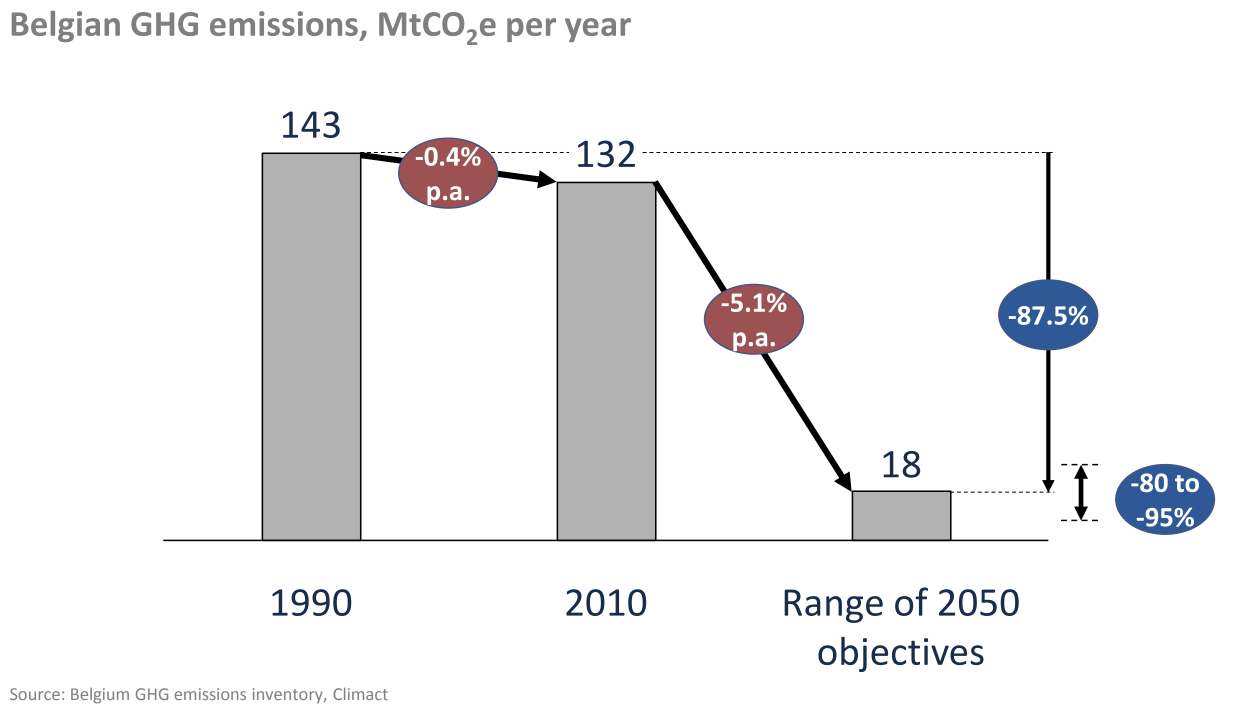

Figure 1. Belgium GHG emissions, historic and range of EU objectives.

Furthermore, decisions made in the next decade, for instance about the replacement of energy infrastructure will have consequences for the next 40 years or more. Choices must therefore be based on an understanding of the long-term challenges. Exploring already the ways in which a 2050 energy system might be configured will help us understand the options available and limit the risk of technological and societal lock-in while taking into account security of supply and price competitiveness.

One primary objective of the study is thus to contribute to the future development of a Belgian Low Carbon Development Strategy (LCDS). Such a LCDS must be in line with the EU long term strategies and provide more clarity to decision makers at all levels on how the long term climate targets can be reached.

At the same time, this study also shares the aim to engage key actors of the Belgian society in the debate on the transition to a sustainable and low carbon society. All sections of society will need to play a part in creating a low carbon economy.

This transition will need to be supported and steered in several ways. It should involve among others a thorough understanding of the current system, determining a desired vision through the participation and engagement of all societal actors, exploring pathways to achieve the desired vision, having short-term and mid-term objectives that will foster achievement of the long-term objectives, and a learning/reflexivity process in order to learn from previous experiences and where necessary redirect the path in a timely manner, given the inherently uncertain context in which we are working.

In this context, the current study provides a basis to mobilise the active participation and engagement of several stakeholders and explore several pathways. Moreover, this exploration of pathways is itself a first basis for the setting of short-term and medium-term milestones. The study is an important first step with a focus on elaborating possible scenarios in a long-term horizon. It also focuses on various techno-economic implications of significant reductions in GHG emissions such as the evolution of primary energy demand, the level of GHG emission by sector, the evolution of the energy mix including the role of the various RES, the investment and operating costs associated to each scenario to name a few.

It is important to highlight that this study is not sufficient to draw specific sector policies. It does however lay out several technically plausible trajectories to reach a low carbon society in Belgium by 2050. While the technical implications of low carbon scenarios are explained in detail, the analysis of the macroeconomic implications of the scenarios, typically their impact on competitiveness and on job creation, is not part of the current work. Although these will be important dimensions to account for when comparing the scenarios, such an analysis requires other methodologies and tools and will be best performed now that the set of technically feasible scenarios has been established. Other questions regarding for instance the social implications or the financing of the transition should be further addressed complementarily to this work.

B. METHODOLOGY AND MAIN ASSUMPTIONS

B.1 Methodology

The study shows that various low carbon pathways are possible and that societal choices are required to properly support the transition to a low carbon society. A long term perspective is essential to support the development of more coherent and coordinated policy. The integration of such an appropriate long term energy vision in shorter term decisions can support the required adaptation of society to a new low carbon realm.

Given the uncertainties arising from a long term horizon as 2050, a scenario approach is used to ensure that a variety of potential outcomes under various assumptions are analysed.

As a first step, a sectoral approach was used to understand what types and levels of change are technically possible in each area. For each emission reduction lever identified in each of these sectors, a range of ambition levels was established so that a wide range of potential futures could be tested.

These levers and the possible ambition levels related to them are the basis of the Belgian version of the OPEERA[2] model, developed to construct possible pathways to 2050. OPEERA is an "Expert-Driven" model developed with the Department Energy and Climate Change (DECC) of the United Kingdom (further described below). The approach looks not only at 2050 as an end point, but also at the sequence of changes that would need to occur over the next 40 years.

Many other analyses and studies already exist based on a variety of methodologies and covering different scopes (by sector, region, country, at European or global level, etc.). Besides a thorough literature review, the study builds extensively on thematic workshops and intensive discussions with a large number of experts in businesses, NGOs, technical fields, and academics. It also pays particular attention to existing Belgian work[3]. More than a hundred experts have also been consulted on several occasions, especially with respect to the ambition levels feasible for each reduction lever (see below in section 'Sector Experts').

In addition to the workshops, formal interactions with the stakeholders took place on several occasions:

- on 20 November 2012, at the yearly annual forum of Belgian Federal Council for Sustainable Development[4], where the sectoral work was presented,
- on 18 February 2013, where preliminary low carbon scenarios were discussed by a 'Consultation Group' (see below in section 'Consultation Group'),
- at several bilateral meetings and discussions with the stakeholders.

The study has built on the comments from the stakeholders also to better identify and understand the key implications for Belgium of a move to a low carbon society. Their contributions are gratefully acknowledged[5].

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[2] OPEERA stands for Open-source Emissions and Energy Roadmap Analysis.

[3] The recently published "Towards 100% renewable energy in Belgium in 2050" study has been used as an input. Regular interactions have taken place between both teams, and VITO is co-authoring both studies.

[4] The presentation is available at http://www.cfdd.be/DOC/fora/energy%202012/Pascal%20Vermeulen.pdf

[5] As mentioned below, the responsibility of the analysis however lies with the authors of the study; the experts and stakeholders consulted do not necessarily endorse the analyses or the conclusions of the study.

Description of the OPEERA Model

The methodology used in this study serves to describe and test various low carbon trajectories or "scenarios" and to understand their key implications. Those scenarios should support policy making by giving an indication of the required evolution of key indicators to reach the GHG reductions: scenarios explore the impact of switching certain group of parameters on/off so as to better understand the impact of certain choices (energy efficiency and lifestyle changes, technological options, etc.).

The OPEERA model, which makes it possible to build these various scenarios, is described in more details in "Appendix 1 – OPEERA model".

It is an "Expert-Driven" model developed with the Department Energy and Climate Change (DECC) of the United Kingdom. Although the model assesses the cost implications of each scenario, based on the evolution of the investments and operational and fuel costs, it is an accounting-type model as opposed to optimisation or simulation models[6]. This means that OPEERA does not adopt a cost optimisation approach and does not identify the least costly way of meeting the 2050 target. The aim instead is to look at what might be practically and physically deliverable in each sector over the next 40 years under different assumptions. OPEERA then allows users of the tool to explore their own choices. Its simplicity, flexibility and transparency make it particularly suitable to engage discussions with stakeholders and other key actors of the transition.

Across all sectors, a large set of levers and trajectories are modelled (more than 100, e.g. transport demand per person; insulation level for refurbished houses; electric steel production; offshore wind capacity) leading to specific energy demand and supply projections. Various ambition levels have been identified and discussed thoroughly for each of these levers and trajectories to describe each sector's current and future GHG emissions.

Four ambition levels have been defined for each lever.[7] They cover a broad range of possibilities, testing the boundaries of what might be technically feasible. They are based on a thorough literature review and extensive expert consultation among businesses, technical fields, NGOs and academics. They are intended to reflect a wide range of potential futures that might be experienced in a particular sector. They are not based on specific assumptions about future policies and their impacts, and should not be interpreted as such. Many stakeholders have been involved in the study, and about 100 of those experts took part in detailed discussions on the definition of the levels. The work aimed to achieve as much consistency as possible across the different sectors in terms of 'level of ambition', so that a 'level 2' effort in one sector would be broadly comparable to a 'level 2' effort elsewhere.

The 4 ambition levels are defined as follows:

- **level 1**: implies a minimum effort, corresponding to the implementation of existing regulation extrapolated with similar trends with no specific additional low carbon efforts, nor the development of unproven low carbon technologies,
- **level 2:** implies a moderate effort, viewed as ambitious but reasonable according to most experts, in line with recent programs in some sectors,
- **level 3:** implies significant efforts, requiring cultural changes, financial investments or significant technology progress, which are unlikely to happen without significant change from the current system,

[6] For a discussion on the comparison of the modelling approaches, see Duerinck (2012).
[7] As an illustration of the various ambition levels, here are the 4 levels for the parameter 'modal split' for passenger transport (p.km): level 1 implies that cars represent a share of 77% ; level 2 a 70% share; level 3 is at 65% and level 4 at 55%.

- **level 4:** implies a maximum physical or technical potential, based on key technical and spatial constraints. It represents a major challenge for society, but not necessarily a complete paradigm shift that would lead us to completely review our consumption/production patterns (e.g., consume only when electricity is available, or produce electricity only based on decentralized resources).

Even at level 2, the consequences of pursuing this effort across several different sectors at the same time will place a high demand on resources and skills, among others. This work is based on the assumption that other countries will be going through a similar transition, which can support higher volumes and significant cost reductions for some of the key technologies, but could also increase the strain on some of the key resources (e.g., lithium for batteries).

The parameters, the levers and their ambition levels are described in detailed tables by sector which are presented in section “C. CONTEXT AND DRIVING FORCES BY SECTOR”. They were submitted to the members of the Consultation Group who provided extensive feedback and they were also presented to the sector experts during the workshops. According to some stakeholders, further lifestyle changes are possible beyond level 4, resulting in even higher ambition levels. These include for example changes related to transport (e.g., reducing personal transport further), buildings (e.g., new housing solutions, adequate insulation and proper temperature management) or consumption patterns (e.g., eating less meat).

Many levers are of a technological nature. This study adopts a conservative approach in the sense that, other than Carbon Capture and Storage and deep geothermal energy sources, only currently available technologies are modelled. Future breakthrough technologies would therefore further ease the low carbon transition.

As in all modelling exercises, not all cross-sectoral impacts and feedback loops can be modelled, but some of the most important ones are included: reductions in energy demand have a direct impact on energy supply, changes in food consumption patterns impact agricultural production levels and the food industry evolution, and changes in transport impact the required fuel levels and have a direct link to the activity level in refineries. Assumptions are made about changes in consumption patterns inside and outside Belgium. For example, it is assumed that if Belgians consume less meat, countries that import Belgian meat also consume less and that the drop in consumption follows the same pace as in Belgium.

The scenario analysis undertaken examines and illustrates the impacts, challenges and opportunities of possible ways of modernizing the energy system. They are not "either-or" options but focus on the common elements emerging and support longer-term approaches to investments.

This flexibility has its downsides: choices on the levels of levers and parameters must be made in a coherent manner since the model itself does not reflect the full complexity of the real world system, and judgments are required to combine various ambition levels or sector trajectories. The users of the model must themselves make these judgements to avoid non-plausible combinations: declining glass manufacturing industry and high levels of additional construction at the same time as a lower demand for freight transport is an example of non-plausible combination. Similarly, the model does not account for all possible feedbacks between different sectors. Changes in one sector might be expected to have a rebound effect in another sector, and not all of these are reflected in the model.

Various key dimensions enable the description of scenarios: evolution of the energy demand, evolution of the energy supply mix including the level of energy imports, exogenous evolutions such as demography evolutions and levels of industry growth, global and European dynamics and evolutions to name a few.

Summary tables are proposed in Section “D. SCENARIOS” to illustrate the chosen ambition levels for the various parameters of the scenarios.

The interactive web-tool, based on the OPEERA model is available at www.climatechange.be/2050. Pre-recorded scenarios, including the five scenarios developed in the study, are available. By simply changing the ambition level of one or several levers, one can build other possible pathways and assess their impact on greenhouse gas emissions and on a series of key variables.

Sector Experts

As mentioned above, the study has benefited from the support of broad range of experts, with whom we interacted in two main ways during the course of the study, through sector work and with a consultation group. These are described below.

Firstly, relevant experts contributed to various sectoral workshops and discussions covering the sectors of transport, buildings, refineries, iron & steel, chemical, pulp & paper, food, bricks & ceramics, non-ferrous, cement, lime, glass, agriculture, energy production and energy distribution which were organized between May 2012 and May 2013.

The workshops gathered expertise and views from the experts and used it as an input to identify the levers and ambition levels. This made it possible to include a diverse range of views and we are grateful for the input we have received. It is worth mentioning that the involvement of these experts does not mean that they necessarily validate all assumptions and results. The processing and interpretation of information exchanged is the consultant's responsibility.

The workshops were designed to mirror the reality of each sector and to understand the GHG drivers:

- covering a view on the context, historical trends and future energy and GHG prospects;
- identifying parameters and theoretical and technical levers that can enter into play to reduce emissions of greenhouse gas emissions;
- describing detailed possible future trajectories (e.g. growth patterns for industrial sectors or detailed process improvements and energy efficiency potentials) and resulting scenarios for Belgium in the global context;
- detailing the ambition levels and associated abatement cost for each of the lever and modelled action;
- identifying the main challenges and opportunities of moving to a low carbon society.

The main workshops results are detailed in Section C.

Consultation Group

Secondly, the study has benefited from the support of a Consultation Group. The role of the Consultation Group[8] was to make remarks and observations on the proposed scenarios all leading to GHG emission reductions of at least 80% in Belgium in 2050 with respect to 1990, in the context of the law on the nuclear phase out. It was composed of four academic members, three representatives of the main stakeholders involved (business, labour and environmental organisations) and three representatives of the regional environmental administrations.

In practice, it was asked to the members to react on:

- the choice of the main parameters and levers to reduce emissions, as well as the levels of ambition of these levers which are the basis for building the scenarios; this interaction took place in written form

[8] See also Appendix 3.

- the scenarios elaborated by the consultants; to that purpose, a workshop was organised on 18 February 2013.

Their contributions are gratefully acknowledged. The reactions and the guidance provided by the members served as an input to the authors of the study to allow them to reinforce the coherence, relevance and usefulness of the scenarios with respect to the low carbon transition challenge.

The final responsibility for the scenario analysis lies with the authors of the study. Therefore, the analyses, the scenarios elaborated and the results of the study do not necessarily reflect the point of view of the Consultation Group members or of the experts consulted during the work. As such, the members of the Consultation Group and the experts consulted do not necessarily endorse the analyses or the conclusions of the study.

Costs methodology

First and foremost, the essential objective behind a GHG emission reduction of 85-90% is to avoid the costly implications of climate change.

Providing a comprehensive estimate of the costs of decarbonisation out to 2050 is very challenging: no one can predict accurately how fuel and technology costs will develop over such a long period. Costs necessarily depend on assumptions about fuel prices, technology development. They also depend on specific policy choices within the country as well as on the paths taken by other countries, on the development of new technological solutions, and on people's behaviour, etc.[9] The whole society will look radically different in 2050 compared to today, and looking back at the available technology and energy usages 40 years ago only confirms this.

Given inherent uncertainties around future costs of technologies and fuels, and the limitations of the approach, the cost estimates included in this work should not be seen as accurate projections: they serve as indications to give a sense of what is at stake as it is particularly difficult to assess precisely the likely future system cost.

The cost of the various scenarios has been analysed rigorously for each sector and each of the levers identified by evaluating the investment costs, operating and maintenance costs and fuel costs:

- investment costs (CAPEX) represent the amounts invested (e.g., construction of a plant or a house, buying new manufacturing equipment, acquiring a car) considering a different lifetime investment;
- the O&M costs are the costs of operations and maintenance;
- the energy costs include the costs of fossil fuels and renewable energy sources as well as the costs of the energy infrastructure (e.g. deployment of interconnections).

Figure 2 gives an overview of the costs that have been scrutinized in the analysis.

[9] Other published studies suggest that the costs of decarbonising are manageable, though they are sensitive to assumptions about the future costs of technologies and fossil fuel prices, and also the underlying structures of the models.

		Investments	O&M	Fuels	Externalities
Buildings	Behaviour changes	n/a	- Maintenance based on technology distribution - Information campaigns, training,…	- Consumption volumes - Taking fuel shift into account - Taxes on fuels	- Impact of climate change - Air quality (cost on health and lower life expectancy) - Congestion costs (transport) - Reduction in noise disturbances (transport) - Visual impact (wind turbines) - Impact on required resources - Preservation of fossil fuel resources - Dependence on new resources - Impact on biodiversity services - Reduction/increase in nuclear risk - Impact of energy (in)dependence (reducing the impact of oil crises, etc.)
	Energy efficiency	▪ Refurbishing (insulation, windows, etc.) ▪ Replacing heaters/boilers ▪ Replacing electric appliances ▪ Improvements of appliances by manufacturers (R&D)			
	Electrification	▪ Replacing boilers			
Transport	Behaviour changes / evolution in organisation of society	▪ Vehicles (cars, buses, trains, lorries, boats) ▪ Rail infrastructure ▪ Costs related to the structure of the territory (for example a reduction in the cost of road maintenance	- Maintenance based on technology distribution - Information campaigns, training,…	- Consumption volumes - Taking fuel shift into account - Taxes on fuels	
	Energy efficiency	▪ Cost of fleet replacement over time ▪ Improvement of fleet efficiency by manufacturers (R&D)			
	Electrification	▪ Replacement by electric vehicles (batteries included) ▪ Cost of the electric charging infrastructure			
Industry	Carbon intensity	▪ Investments to improve carbon intensity (new products or processes, energy efficiency, cogeneration, etc.)	- Maintenance based on technology distribution	- Consumption volumes - Taking fuel shift into account -Functioning of CCS	
	CCS	▪ Equipment to capture, transmit and store CO_2 ▪ Cost of R&D of developing CCS			
Power	Electricity	▪ All production plants (wind or gas turbines, etc.) ▪ Electric transmission network, back-up plants ▪ Distribution network (simplified approach) ▪ Cost of CCS for electricity ▪ Cost of R&D for geothermal systems	- Maintenance based on technology distribution	- Biomass, fossil fuels and electricity imports - Cost of producing biomass	
	Biomass	▪ Biomass transformation plants			

▪ Included
▪ Non-included

Figure 2. Structure of the cost elements.

The system cost is computed in real terms (constant Euros) and accounted for when these costs are incurred by the various agents. For example, the costs of renovating the building stock are spread over the years of renovation and the operating costs over the years of operation.[10] The analysis is made without discounting these values, simply taking them in real terms when they are incurred. Nonetheless, section "F.2 Overall system cost implication of the low carbon transition" illustrates the impact of discounting the costs.

The assumptions on fossil fuel prices are important. There is a high uncertainty on the future evolution of fuel prices and evolution of international energy prices is highly dependent on fuel reserves (including non-conventional gas), level of global economic development, and political action on energy and climate change. For this study, the fuel prices are based on the IEA ETP 2012 scenarios, and can be found in Figure 3.[11]

[10] This skews the cost results as investments made in the latter part of the period studied or around 2050 will lead to fuel economies after 2050 which will not be accounted for in the model. However, this will be true in both the reference and the low carbon scenarios, which all have significantly lower consumption in the buildings sector.
[11] IEA ETP 2010 and 2012, WWF "The energy report", ECF 2050 Roadmap.

USD/EUR (real)	Histo-rical	IEA ETP 2012 2DS scenario		IEA ETP 2012 4DS scenario		IEA ETP 2012 6DS scenario		Highest global energy demand scenario	
	2010	2030	2050	2030	2050	2030	2050	2030	2050
Oil (Crude oil imports, USD/barrel)	78	97	87	117	118	134	149	170	200
Coal (OECD steam coal imports, USD/t)	99	74	60	109	109	116	126	130	150
Gas (EU imports, USD/mmBTU)	7	10	8	12	12	13	14	16	20
Uranium EUR/MWh	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

SOURCE: IEA ETP2012, WWF « The energy report», ECF 2050 Roadmap, Climact

Figure 3. Evolution of fuel prices used in this study.

Prices of the IEA 6°C scenario are used for the reference scenario. In contrast, the low carbon scenarios that should lead to keeping the global increase below 2°C are logically built based on the IEA 2°C scenario which assumes that these targets are reached globally. These prices therefore derive from the IEA projections of a global effort to halve GHG emissions by 2050, triggered by increasing carbon values. This is the best reflection of the underlying forces that are assumed to play out in these drastically different scenarios and leads to more attractive fossil fuel prices in the low carbon scenarios, and thus lower fossil fuel costs. The actual impact is however limited on these low carbon scenarios since the amount of fossil fuels consumed is significantly reduced by 2050.A sensitivity analysis is performed nevertheless in section “F.3 Sensitivities” to illustrate the impact of the energy price assumption on the main results.

No carbon price is specifically assumed in our study. In the low carbon scenarios, the cost required to implement all low carbon levers is included, but no carbon price (the price required to implement the most expensive technologies required compared to their alternative) is computed. Macro-economic implications of such carbon prices are not included in this report; other models are better suited to test the implications from a country perspective (Which are the best alternatives to lead to carbon reductions: auctioned permits, taxes, mandated targets, etc. and how potential revenues collected can be best reinjected in the economy and distributed across the various agents).

Our analysis does not include behavioural change or R&D costs nor does it include disutility costs.[12] Costs from the various potential externalities are not included in the costs analysis, even though these can be significant since low carbon scenarios positively impact air quality, health, biodiversity. Co-benefits, e.g. on health and other environmental aspects (water, biodiversity, ocean acidification to name but a few), are also not included in the study.

[12] The potential impact of "utility" or enjoyment related to the different services is not modelled. Some models recognize such an explicit reduction in services such as personal travel cost. It is assumed that individual well-being is not significantly affected by the different levers.

Finally, future breakthroughs[13] that can be imagined on a 40-year time-horizon, in technology but also in behavioural changes and in the way society is organized are not included. These could accelerate the transition and further reduce the costs.

This analysis is not a macro-economic analysis: potential impacts on GDP, competitiveness, total import/export balance or jobs are not included. This requires models of a different type (typically a macro-economic model). Impacts from the low carbon transition on the economic activity can be positive or negative depending on key assumptions, as well as on how a potential carbon tax would be used by public authorities. We refer for example to the work by ECF in their *Roadmap 2050*[14] work for a detailed description of such a model and of potential implications for Europe. We also encourage public authorities to perform such an analysis before taking specific decisions on future policies.

B.2 Scope and limits

Emissions scope

The accounting of emissions is made on a territorial basis: only greenhouse gases emitted in Belgium are taken into account. Consumption-based approaches including the carbon embedded in imported goods are more comprehensive and they reflect the actual carbon footprint of Belgian citizens. However, methodological uncertainties in measuring the carbon content of imported and exported goods are significant and the current political processes at the international, European and national levels are based on a territorial approach (greenhouse gas inventories).

It is fundamental to highlight that this work does not assume a reduction in Belgian industrial activities in order to reach lower territorial GHG emissions. On the contrary, it highlights ways to decarbonise Belgium while supporting a flourishing industry. While highly uncertain, industry production trajectories have been formed following discussions with representatives from industry, academics and analysis of relevant literature. A wide range of scenarios were discussed and aligned based on the comments of the industry federations, reflecting different technological assumptions and approaches.

Following the IPCC guidelines, emissions resulting from fuels sold for international maritime and aviation transportation should not be included in national inventory totals, but should be reported separately as emissions from “bunkers” or “international bunkers.” They will be included in the model for completeness. However, as these sectors are expected to have their own targets set at international level, they will not be included in the Belgian 80-95% GHG emission reduction scenarios. It is worth mentioning though that maritime transportation has a significant impact on the Belgian refining industry.

While the model looks specifically at Belgium, it also includes assumptions for potential international imports of energy/bioenergy and more specifically electricity, and integrates the results from the European modelling on electricity balancing by ECF in their Roadmap 2050.

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[13] In such a time-horizon, one can think of completely new industrial and services processes such as steel from electrolysis, advanced paper drying technologies, large scale conversion of oil refineries into bio refineries, advanced biomass & waste energies, 3D printing for transport, flexibility in energy demand for industries, switch to a functional economy, highly flexible organisation of work etc.

[14] http://www.roadmap2050.eu/.

Carbon leakage

The analysis implicitly assumes that either all countries around the world do engage in comparable efforts or that the appropriate measures are taken at the European and national levels to prevent any risk of carbon leakage.

The international context will have a significant influence on what happens in Belgium in terms of the development, supply and price of technologies and fuels. This work does not attempt to assess what specific shape these international developments will take but builds on the assumption that Belgium is not isolated in its decarbonisation effort. Reaching the objective of limiting the average global temperature increase to maximum 2°C requires all countries operating their transition towards low carbon societies. We implicitly assume that parameters and costs of the low carbon scenarios are coherent with a global effort towards the 2°C objective.

One key dimension that is potentially impacted by such an assumption is the issue of carbon leakage. Risks of carbon leakage are partly mitigated if all countries make comparable efforts in the long run.[15] However, this matter needs to be closely monitored and addressed. This is particularly the case if the EU moves more quickly than others. It then becomes imperative to adopt the right instruments to prevent any risk of carbon leakage, which would be completely counter-productive in terms of global emission reductions.

Given the scope of this study focusing on the elaboration of scenarios, aspects of competitiveness and carbon leakage risks are not assessed. It is therefore implicitly assumed that the appropriate instruments are in place to prevent it.

Although this study only deals with emissions on the Belgian territory, it is clear that one of the key instruments to tackle emissions from industries is the EU Emissions Trading System (EU ETS) which guaranties a level-playing field for European companies. Decarbonisation of industry will affect the core processes in a sector that is at the same time unevenly exposed to global competition. Preventing carbon leakage should be at the heart of climate policies: a delocalization of carbon-intensive industrial activities outside of Belgium in other regions with less stringent climate policy regimes is detrimental to reaching global GHG emission reduction goals. GHG emission reduction percentages in industrial sectors in Belgium should not be interpreted as proposals for binding targets for these sectors but rather figures that reflect possibilities for emission reduction.

[15] A wide array of regions/countries/cities have performed long term low carbon analysis and mitigation plans. Large non-European countries include for example: Brazil, China (http://2050pathway-en.chinaenergyoutlook.org/), Indonesia, Japan, Mexico, South Africa, South Korea.

C. CONTEXT AND DRIVING FORCES BY SECTOR

This section summarizes extensive work from the authors and discussions held during workshops on each of the sectors. The workshops have helped characterise the GHG and energy structure and the evolution in each of the sectors. The content has been shared and reviewed with the experts and has been enriched based on numerous interactions. The sector work represents several hundreds of slides, shared with the experts and the stakeholders and available on request at the Climate Change Unit of the Federal Public Service Health, Food Chain Safety and Environment.

C.1 Historic GHG emissions in Belgium

The source for historical emissions is the Belgium's National Inventory Report or NIR which captures current (and historic) GHG emissions in Belgium for the different emission sources. This inventory contains greenhouse gas emissions estimates for the period 1990 to 2010 for Belgium, and describes the methodology on which the estimates are based.[16]

Emissions dropped by ~8% between 1990 and 2010. This is due mainly to reduction in the energy production industries and in the other industrial sectors. During the same period, emissions in both Transport and Buildings grew significantly by 18% (see Figure 4).

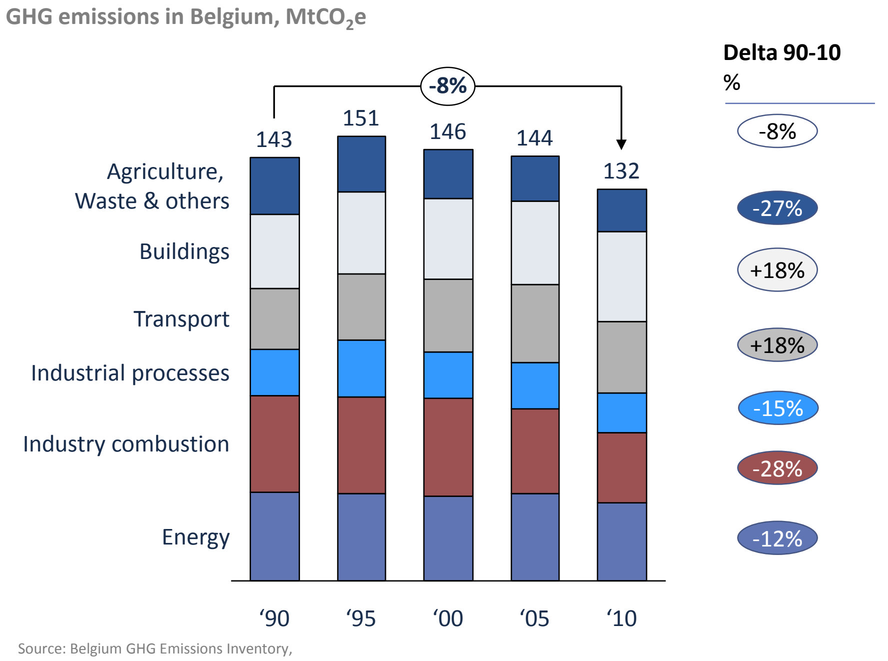

Figure 4. Belgium, GHG emissions by sector, Evolution 1990-2010.

By 2010, electricity production, industry, buildings and transport represented over 90% of the emissions, each with a share between 18% and 28%. Agriculture covered most of the remaining 10%.

[16] This report and the Common Reporting Format (CRF) tables are compiled in accordance with the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines on annual inventories. The Belgian Interregional Environment Agency (CELINE - IRCEL) is responsible for integrating the emission data from the inventories of the three regions of Belgium and for compiling the national inventory. Transport, fluorized gases and LULUCF data are currently obtained through different channels. The aggregation is performed using Aggregator (a European commission tool which also consolidates the NIR CRF from member states).

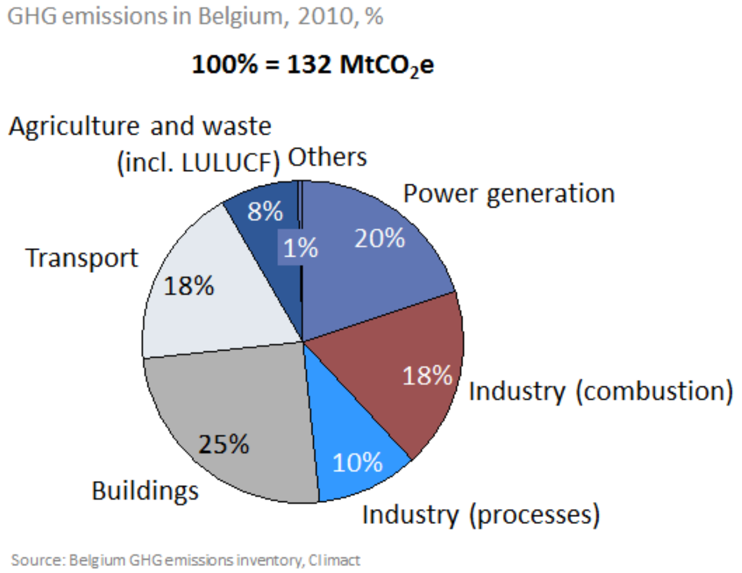

Figure 5. Belgium 2010 GHG emissions by sector.

C.2 Transport sector

Context

The transport sector is society's nervous system. It plays a facilitating role for the economy and the quality of life of citizens as it procures freedom to travel, access to jobs, education, leisure and health while enabling the transport of goods. It has numerous interactions with other sectors which have not always been possible to capture due to the methodology used in this work.

The main dimensions driving energy consumption and GHG emissions from transport in Belgium are population growth, the evolution of passenger transport demand, the evolution of the amount of transported goods, transport modal shares and the technical choices for each transport mode. In Belgium, the high density of the transport network is considered as an asset e.g. to develop logistic activities.

Transport is one of the main energy consuming sectors in Belgium and represents about a quarter of the overall energy consumption. Historically, it has been difficult to uncouple strong economic growth and transport demand: transport GHG emissions represented 18% of the total GHG emissions in 2010. Furthermore, while total GHG emissions in Belgium dropped by ~8% between 1990 and 2010, transport emissions rose 18% during this period, mainly due to a 30% increase in distances travelled. They represent 25 $MtCO_2e$, 4 $MtCO_2e$ more than in 1990, with more than 80% of transport GHG emissions originating from road transport, mainly fossil fuel based.

The transport sector covers domestic passenger transport, domestic freight transport as well as international aviation and maritime transport. The methodology in this study follows the IPCC guidelines, which recommends reporting separately international aviation and maritime transport GHG emissions. Even if they are included in the model for completeness, international aviation and maritime transport must follow targets set at international level and hence will not be included in the Belgian 80-95% GHG emission reduction scenarios.[17]

[17] Historically, emissions from international aviation did not represent a major part of the overall Belgian GHG emissions. However, looking at the 80% or 95% reduction targets for the other sectors, the GHG emissions of the sector could represent between 15% and 60% of the

To abate transport GHG emissions, the challenge is to mitigate demand while supporting economic activities and managing the implications outside the transport system (e.g., urban planning, congestion, impact on health, etc.). This is particularly relevant for Belgium, in view of the country's important role in the European and international transport systems.

Driving forces – domestic passenger transport

Most domestic passenger travel is for three key purposes:[18] in 2010, commuting and education accounted for 33% of the number of trips; leisure trips for 47%; and shopping for 20%.

Mitigating energy consumption and emissions of the transport sector can be achieved through a mix of behavioural changes and technical changes.

On the behaviour/societal organization side, the key is to mitigate demand structurally by addressing all transport purposes and increasing the vehicle occupation, combined with a shift from cars to softer transport modes. The objective is to reduce the extent and cost of the technical changes (mainly by limiting the size of the car fleet and the consequently diminishing reliance on massive energy efficiency improvements). Various measures may be considered to mitigate demand for transport e.g., telecommuting or measures to facilitate home-work proximity. Some countries including America, Britain, France and Sweden have already seen lower transport demand and a growing body of academics cite the possibility that both car ownership and vehicle-kilometres driven may be reaching saturation in developed countries.[19] Evidence is also emerging of new types of relationship to car ownership and growing tendency to view cars as appliances, not aspirations.[20]

Technical improvements will also be required for greater vehicle efficiency, including changes in the powertrain and in the size and weight of the vehicles, leading to ~30% to ~50% reductions in fuel consumption. Other evolutions area shift from ICE to alternative powertrains such as plug-in hybrid, battery electric, CNG and fuel cell electric cars and buses.

It is clear that a smaller car fleet would have other side benefits such as fewer traffic jams, and that a shift to electric powertrains would support lower air pollution in cities, as well as lower noise pollution.

The modelled levers for domestic passenger transport cover:

- transport demand per person for all modes ranging from an increase of ~20% in 2050 vs. 2010 in level 1 to a decrease of ~20% in level 4;
- modal split: level 1 foresees a stabilization of the various modal shares at the 2010 level, with a 77% share for cars while level 4 sees a reduction of the car share to 55%, an increase of walking and cycling to 6%, an increase to 13% and 25% for train and buses respectively;

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remaining emissions and would need to be properly addressed. See '2006 IPCC Guidelines for National Greenhouse Gas Inventories', http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

[18] Belgian Daily Mobility BELDAM, Transportation elasticities, Victoria Policy institute (2011).

[19] The Economist, 20 April 2013, A special report on the future of the car, http://www.economist.com/node/21563280, and for the sources used for this report http://www.economist.com/node/21576210/sources-and-acknowledgments

[20] A New Direction Our Changing Relationship with Driving, U.S. PIRG Education fund frontier group, T. Dutzik, P. Baxandall, spring 2013, http://www.uspirg.org/sites/pirg/files/reports/A%20New%20Direction%20vUS.pdf. See also the recent study of the insurance group Allianz 'Inter-connectedness is revolutionizing mobility habits' available at https://www.allianz.com/v_1369214563000/media/press/document/1305-Risk-Pulse-Mobility-EN.pdf.

- occupation level of vehicles: level 1 is based on a further 5% decline of the number of passengers per car combined with a 10% increase in occupation levels of bus and trains. Level 4 assumes an increase of 16% for cars, 33% for trains and 50% for buses (vs. 2010);
- vehicle efficiency for cars: level 1 stabilizes the emission of the ICE[21] vehicles at the EU target level for 2020 and the same energy efficiency improvement level for EV while level 4 assumes halving the emission level for ICE vehicles and ~60% improvement efficiency for EV;[22,23]
- technology evolution: level 1 assumes that 25% of the cars are EV or plug-in hybrids by 2050 while level 4 assumes that 80% of the cars are battery electric and 20% are fuel cells vehicles.[24]

Driving forces – domestic freight transport

Since 2000, Belgium has decoupled GDP growth and transported volumes of goods more strongly than before. GDP growth still induces an increase in transport but the link becomes smaller and is impacted by various factors such as the structure of economic activity: the transport requirements of the tertiary sector are not the same as those of industry.[25] A range of factors might have contributed to this recently observed trend and it is not yet clear whether it will continue into the future. This uncertainty has been reflected in the 4 freight transport activity levels.

In a way similar to domestic transport, the following levers are modelled to assess emissions from domestic freight: evolution of demand for freight; evolution of the shares of the different transport modes; evolution of the technologies used for freight transport; energy efficiency of the various technologies.

The modelled levers for domestic goods transport cover:

- demand for goods transport: level 1 assumes a growth of 60% of the volume transported in 2050 vs. 2010 while level 4 assumes a growth of ~10%;
- modal split: the volume's growth is mostly absorbed by road transport in level 1 while level 4 assumes that road transport covers the same volumes as in 2010 and the increase of transported volumes is covered by rail and inland waterways;
- energy efficiency: level 1 and 4 assume a ~10% and ~35% energy efficiency improvement respectively for fuel combustion lorries;
- shares of the different transport modes: level 1 foresees that 90% of the goods will be transported by diesel lorries and 10% by natural gas while level 4 is based on 35% diesel lorries, 45% natural gas lorries and 20% electric lorries;
- Biofuels: part of the diesel share will be replaced by biofuels. We assume that 2020 target levels for biofuels in transport are achieved (10,14% of final energy demand). This absolute[26] level of biofuels is maintained in level 1, and doubled in level 4. These would likely be from the first generation type until 2020, and switch over time to the second generation.

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[21] ICE: Internal Combustion Engines. EV: Electric Vehicle.
[22] Fuel Cell Electric Vehicles follow the same pattern as EVs while having a lighter weight.
[23] For buses and trains, level 1 assumes a 10% to 15% improvement in energy efficiency and level 4 assumes 30% to 40% energy efficiency improvement.
[24] For buses, level 1 assumes 30% plug-in hybrids or EV and and level 4 assumes 75% plug-in hybrids/EV and 5% fuel cells.
[25] According to Eurostat, the index of the volume of goods transported per unit of GDP gas decreased by ~30% in 2010 over 2000.
[26] Even if final energy demand decreases in the low carbon scenarios, absolute volumes of biofuels are assumed to stabilize or increase.

Ambition levels for transport levers

	Lever	Description	1	2	3	4
Domestic passenger transport	XII.a					
	(i) Demand	Transport demand per person for all modes (passengers.km, walking, cycling, public transport, passenger cars); occupation levels of the vehicles	Transport demand per person increases by ~20%; occupation level of cars decreases by ~5%; occupation levels of buses and trains increase by ~10%	Transport demand per person increases by ~10%; occupation level of cars increases by ~5%; occupation levels of buses increase by ~20% and trains by ~15%	Transport demand per person decreases by ~10%; occupation level of cars increases by ~10%; occupation levels of buses increase by ~33% and trains by ~25%	Transport demand per person decreases by ~20%; occupation level of cars increases by ~15%; occupation levels of buses increase by ~50% and trains by ~33%
	(ii) Modal shift	Transport demand across the different modes. In 2010 the shares were as follows : Walking / Biking: ~3%, Car: ~77%, Bus: ~13%, Rail ~7%	Shares of the different modes in 2050 remain comparable to 2010 levels (Walking / Biking: ~3%, Car: ~77%, Bus: ~13%, Rail ~7%)	Share of walking and cycling increases to ~4%; Share of bus / coaches increases to ~17%; Share of rail increases to ~9%; Share of cars decreases to ~70%	Share of walking and cycling increases to ~4,5%; Share of bus / coaches increases to ~20,5%; Share of rail increases to ~10%; Share of cars decreases to ~65%	Share of walking and cycling increases to ~6%; Share of bus / coaches increases to ~25%; Share of rail increases to ~13%; Share of cars decreases to ~55%
	(iii) Energy efficiency	Evolution of the energy efficiency, defined as the energy use per unit of transport for the different types of technologies of the different types of vehicles. This includes evolutions of the power train, capacity changes, evolutions of the size and weight of the vehicles (up- an down-sizing), etc.	- Fuel combustion efficiency of cars improves by ~19%; - Plug-in hybrids and electric cars efficiency improves by ~30%; - Fuel combustion, hybrid and electric buses efficiency improves by ~15%; - Rail transport efficiency improves by ~10%	- Fuel combustion efficiency of cars improves by ~40%; - Plug-in hybrids efficiency improves by 40-45% and electric cars efficiency improves by ~45%; - Fuel combustion, hybrid and electric buses efficiency improves by ~20%; - Rail transport efficiency improves by ~20%	- Fuel combustion efficiency of cars improves by ~45%; - Plug-in hybrids efficiency improves by 45-50% and electric cars efficiency improves by ~50%; - fuel combustion, hybrid and electric buses efficiency improves by ~25%; - Rail transport's efficiency improves by ~30% for diesel and by ~25% for electric traction	- Fuel combustion efficiency of cars improves by ~50%; - Plug-in hybrids efficiency improves by 50-55% and electric cars efficiency improves by ~55%; - fuel combustion, hybrid and electric buses efficiency improves by ~30%; - Rail transport's efficiency improves by ~40% for diesel and by ~30% for electric traction
	(iv) Technology mix / electrification	Electrification level of domestic passenger transport through increased use of plug-in hybrids, battery and fuel-cell electric vehicles	2050 Transport system electrification: - 20% of cars are plug-in hybrids (20% of buses), - 5% of cars are battery electric (10% of buses)	2050 Transport system electrification: - 55% of cars are plug-in hybrids (30% of buses), - 10% of cars are battery electric by 2050 (20% of buses)	2050 Transport system electrification: - 32% of cars are plug-in hybrids (40% of buses), - 39% of cars are battery electric (22% of buses), - 9% of cars are fuel cell (3% of buses) vehicles	2050 Transport system electrification: - 80% of cars are battery electric (30% of buses), - 20% of cars are fuel cell (5% of buses), - 45% of buses are (plug-in) hybrids
Domestic freight transport	XII.b					
	(i) Demand	Evolution of demand (in tonne-km) for freight transport	Transported freight volumes increase by ~60% between 2010 and 2050	Transported freight volumes increase by ~45% between 2010 and 2050	Transported freight volumes increase by ~20% between 2010 and 2050	Transported freight volumes increase by ~10% between 2010 and 2050
	(ii) Modal split	Evolution of the shares of the different transport modes (in % of tonne-km) between 2010 and 2050. In 2010, the shares are of ~70% for trucks, ~13% for rail and ~17% for inland waterways	By 2050, the transport mode shares evolve as follows: - trucks' share increases to from 70 to 75%, - rail's share decreases from 13 to ~12%, - inland waterways' share decreases from 17 to ~13%	By 2050, the transport mode shares evolve as follows: - trucks' share remains at ~70%, - rail's share remains at ~13%, - inland waterways' share remains at ~17%	By 2050, the transport mode shares evolve as follows: - trucks' share decreases from 70 to ~65%, - rail's share increases from 13 to ~15%, - inland waterways' share increases from ~17 to ~20%	By 2050, the transport mode shares evolve as follows: - trucks' share decreases from 70 to ~55%, - rail's share increases from 13 to ~20%, - inland waterways' share increases from ~17 to ~25%
	(iii) Energy efficiency	Evolution of the energy efficiency, defined as the energy use per unit of transport for the different types of technologies of the different types of vehicles. This includes evolutions of the power train, capacity changes, evolutions of the size and weight of the vehicles (up- an down-sizing), etc.	Efficiency of fuel combustion trucks improves by ~10%; efficiency of diesel and electric trains improves by ~10%	Efficiency of fuel combustion trucks improves by ~15%; efficiency of diesel and electric trains improves by ~20%	Efficiency of fuel combustion trucks improves by ~25%; efficiencies of diesel and electric trains improve by ~30% and ~25% respectively	Efficiency of fuel combustion trucks improves by ~35%; efficiencies of diesel and electric trains improve by ~40% and ~30% respectively
	(iv) Technology mix / electrification	Evolution of the technologies used for trucks (diesel/CNG/electricity) and trains (diesel/electricity)	The trucks technology share is ~90% diesel (hybrid) trucks, ~10% CNG (hybrid) trucks; the trains technology share is similar to 2010 with 45% diesel trains and 55% electric trains	The trucks technology share is ~70% diesel (hybrid) trucks, ~25% CNG (hybrid) trucks and ~5% electric trucks; the trains technology share is 35% diesel trains and 65% electric trains	The trucks technology share is ~52% diesel (hybrid) trucks, ~38% CNG (hybrid) trucks and ~10% electric trucks; the trains technology share is 45% diesel trains and 55% electric trains	The trucks technology share is ~35% diesel (hybrid) trucks, 45% CNG (hybrid) trucks, and ~20% electric trucks; the trains technology share is 10% diesel trains and 90% electric trains.

Table 1. Levers and ambition levels for Transport.

C.3 Buildings

Context

GHG emissions in Buildings, which represented 25% of the total GHG emissions in 2010, increased significantly between 1990 and 2010. They represented 33 MtCO2e in 2010, almost 4 MtCO2e more than in 1990. Within Buildings, the residential sector represents the vast majority of the GHG emissions. Direct GHG emissions in the residential and services sector are due to the combustion of fossil fuels used for the heating of buildings and sanitary water, while indirect emissions are caused by the demand for electricity used for lighting, appliances, cooling & heating. All of these energy services are important fulfil essential needs and/or maintain/raise the temperature levels afforded by our built environment (heating, cooking, hygiene, etc.). In addition, with about 76% of GDP, the services sector (including public administration) represents is a major part of the Belgian economy. As a consequence, smart energy demand mitigation should occur in those sectors while still guaranteeing their essential contribution to human needs and economic welfare.

The built environment is one of the main energy consuming sectors in Belgium, about 34% of the overall final energy consumption in 2010. In contrast to the performance of the overall Belgian economy, GHG emissions in the built environment increased significantly by 18% over the period 1990-2010 (compared to -8% for Belgium as a whole). This rise was mainly caused by demographic evolutions (the number of households grew by +13% from 1995 to 2010) and output growth of the services sector (+35% from 1995 to 2010). The relatively[27] poor performance of the building envelope of the Belgian residential building stock (residential buildings existing in 2010 consumed an average of about 139 kWh/m² heated compared, for instance, to ~50 kWh/m^2 in Germany[28]). This points to a large potential for reducing future GHG emissions.

Driving forces in the built environment have been modelled separately for heating, hot water & cooling and lighting and appliances. Population growth and economic growth are exogenous drivers common to all sectors, as well as the rate of demolition of existing buildings.

Energy consumption of the buildings sector is strongly correlated to seasonal and annual variations in weather conditions. The degree-days concept neutralizes this weather variation impact and the simplified assumption has been made that the average weather in 2050 will be comparable to the average weather in the period 2000-2009.[29]

Driving forces – heating, hot water and cooling

Key drivers for heating, hot water and cooling demand are population growth (increase in the number of inhabitants and households) for the residential buildings, economic growth (expressed as added value) for the commercial buildings, size and compactness of buildings, the evolution of heating & hot water demand per household (or per added value in the services sector) related to the performance of the building envelope, the specific heating or cooling technologies used (and the related fuel mix), and finally, the expected heating/cooling demand level of households (behavioural driving force).

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[27] Buildings Performance Institute Europe (BPIE), Europe's buildings under the microscope - A country-by-country review of the energy performance of buildings, October 2011.
[28] Ibid.
[29] 1799 degree days (15/15), Uccle.

- **Heating/cooling level**: the demand is determined by the average internal temperature, the demand for hot water and the cooling demand. The scenarios cover a range of assumptions for these parameters:
    - Average internal temperature in households (average of heated and non-heated rooms in dwellings) ranges from 20°C (level 1) to 16°C (level 4) in 2050, compared to 18°C in 2010;
    - The demand for hot water for sanitary purposes ranges from an increase of +20% (level 1) to a decrease of -50% (level 4) in 2050 compared to the situation in 2010 (the demand in the services sector is assumed to remain constant);
    - The demand for cooling in household's ranges from 60% of households equipped with air-conditioning in 2050 (level 1) to keeping 2010 levels constant at 4% of households (level 4). For commercial buildings the use of air-conditioning ranges from 33% to 90% in 2050, compared to 66% of commercial buildings equipped with air-conditioning now.

- **Performance of the building envelope:** determined by the renovation speed and the insulation level and air tightness of new dwellings and commercial buildings:
    - Regarding the renovation speed, the scenarios cover a range between 40% (level 1) and 100% (level 4) of existing buildings renovated by 2050. Depending on the ambition level, the renovations only marginally improve the existing building stock (to an average level of heat demand of 111 kWh/m² - level 1) or convert renovated buildings into very low energy buildings (average heat demand of 30 kWh/m² - level 4);
    - New buildings are assumed to be built according to very low energy house standards (average heat demand of 30 kWh/m²) or 'passive house' standards (average heat demand of 15 kWh/m² - level 4) as of 2020 depending on the ambition level.

- **Urban planning** can influence the compactness of the new housing stock as determined by the share of flats. Depending on the ambition level, 40% to 77%[30] of the Belgian population is assumed to live in flats in 2050.
- **The choice of heating technologies** determines the fuel mix used in households and the services sector, and thus has a direct influence on the GHG emissions. Two drivers are modelled:
    - The level of electrification of heating technologies, which reflects the use of heat pumps. Depending on the ambition level, 20% (level 1) to 85% (level 4) of the installed heating technologies in residential and commercial buildings will be heat pumps in 2050;
    - The installation of alternative non-electric heating technologies (district heating with CHP or heat from power stations, micro-CHP, geothermal energy), ranging from 10% to 40% of the non-electric heating installations in 2050, depending on the ambition level.

Driving forces – lighting and appliances

Key drivers for the lighting and appliances sub-sector are also population growth (increase in the number of inhabitants and households) for residential buildings, economic growth (expressed as added value) for the commercial buildings and the evolution of lighting and appliances (or per added value in the services sector) related to the increased wealth and the development of new appliances used.

We assume the following possible evolutions:

[30] In urban area, the share of flats in new buildings currently amounts to about 75%.

- **Lighting** has a very large technical potential, and new lighting solutions are already coming fully into force throughout the EU. We assume that the reference case already reflects a decrease of ~-40% in energy demand for lighting per household**.** This reduction strengthens to -50, -60 and -70% in levels 2, 3 and 4.
- For **domestic (or white) appliances** two trends play against each other: more appliances tend to be used per household on average, but they are becoming more and more efficient. We assume 0% growth in the demand per household in the reference case, and -5%, -10% and -20% in levels 2, 3 and 4.
- The uncertainty around the evolution of demand for **small (or black) appliances** is particularly high. New possibilities for these type of appliances are endless (TVs, computers, tablets, smart homes, etc.), but they also become increasingly efficient. We assume 12.5% growth in the demand per household in the reference case, and 0%, -12.5% and -25% in levels 2, 3 and 4.

Ambition levels for buildings levers

		Lever	Description	1	2	3	4
Home heating, hot water and cooling	IX.a	**Home heating, hot water & cooling**					
		(i) Compactness	Compactness of new housing stock determined by the share of flats in the new built housing stock	An important share of the people tends to live and work in suburban and rural areas. This decreases the share of flats from the current 53% to 40% by 2030. The share remains constant after 2030)	The share of flats in new housing stock remains constant at 53%	Part of the population moves to urban areas. This increases the share of flats in new housing stock until 2030 from 53% up to 60%. The share remains constant after 2030	An important share of the people tend to live and work in urban areas, resulting in more urbanisation. The current trend of increased urbanization is extended, with a 1,2% increase in the share of flats in the total of new houses per year up to 77% in 2030. After 2030 the share of flats remains at that level which is typically reached in urban areas nowadays
		(ii) Heating/Cooling	Energy demand is determined by the average internal temperature by households, the hot water and the cooling demand	Average internal temperature in households rises to 20ºC by 2050; there is a 120% increase in hot water demand for sanitary purposes per household in 2050; the penetration of heat pumps increases - which can also be used as cooling device-; cooling reaches 60% of the households by 2050 compared to 4% today	Average internal temperature in households rises to 19ºC by 2050; the hot water demand per household is kept at current level; 40% of Belgian households effectively uses air conditioning by 2050	Average internal temperature in households keeps constant at current level, namely 18ºC; there is a 20% decrease in hot water demand per household in 2050; 20% of Belgian households effectively uses air conditioning by 2050	The average internal temperature in households falls to 16ºC by 2050; there is a -50% decrease in hot water demand for sanitary purposes per household in 2050; the total cooling demand of Belgium is kept around current level (~4% of households)
		(iii) Housing thermal efficiency	Improving the insulation level and air tightness of dwellings will lower the energy demand for heating for new dwellings and refurbished houses	Renovations: minor improvements - application of low cost or easy to implement measures resulting in heat demand decrease from ~140 to ~110 kWh/m² in 2050. New houses: starting from the 2010 EPB legislation which requires a max consumption of 99 kWh/m² for a new house, the final demand of each new dwelling will decrease to 'very low energy house' standard (30kWh/m²) by 2020	Renovation: effort resulting in heat demand decrease from ~140 to ~99 kWh/m². New houses: starting from the 2010 EPB legislation which requires a max consumption of 99 kWh/m² for a new house, the final demand of each new dwelling will decrease to 'very low energy house' standard (30kWh/m²) by 2020 and to the level of 'a passive house' (15kWh/m²) by 2040	Renovation: effort leading to low energy houses and resulting in heat demand decrease from ~140 to 60 kWh/m² New houses: starting from the 2010 EPB legislation which requires a max consumption of 99 kWh/m² for a new house, the final demand of each new dwelling will decrease to 'very low energy house' standard (30kWh/m²) by 2020 and to the level of 'a passive house' (15kWh/m²) by 2030	Renovation: effort leading to the "very low energy houses" and resulting in heat demand decrease from ~140 to 30 kWh/m² New houses: starting from the 2010 EPB legislation which requires a max consumption of 99 kWh/m² for a new house, the final demand of each new dwelling will decrease to the level of 'a passive house' (15kWh/m²) by 2020
		(iv) Electrification	Level of electrification of heating technologies based on heat pumps	By 2050, 20% of the installed heating installations in the residential stock are using heat pumps (running on electricity)	By 2050, 40% of the installed heating installations in the residential stock are using heat pumps (running on electricity)	By 2050, 60% of the installed heating installations in the residential stock are using heat pumps (running on electricity)	By 2050, 85% of the installated heating installations in the residential stock are using heat pumps (running on electricity)
		(v) Alternative heating technology	Installation of alternative heating technologies: district heating with CHP/cogeneration or heat from power stations, micro-CHP, geothermal energy except from electric heating (heat pumps)	Alternative technologies represent 10% of the non-electric heating installations	Alternative technologies represent 20% of the non-electric heating installations	Alternative technologies represent 30% of the non-electric heating installations	Alternative technologies represent 40% of the non-electric heating installations
Home lighting and appliances	X.a	**Home lighting, appliances and cooking**					
		(i) Demand / Efficiency	Electricity demand for lighting and appliances per household	A stabilization in electricity demand per household due to: 1. a decrease in total demand of energy for lighting of -40% as efficiency levels drastically improve with new technology; 2. a stabilization of demand from white appliances with increased population and increased efficiency (0%); 3. an increase in demand from black appliances by 12.5% by 2050;	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	A decrease in electricity demand per household in 2050 by -30% due to : 1. lights are replaced with extremely efficient lights (such as LEDs at 75 lumens/watt), leading to ~70% lower demand per household; 2. white appliances are replaced with extremely efficient one by 2050, leading to -20% electricity demand per household; 3. when replacing consumer electronics and home computing products, only the best practice products are adopted until 2050 leading to ~50% decrease in efficiency per product. An increase of the penetration level of 50% of these products is assumed, altogether leading to -25% electricity consumption;
		(ii) Electrification	Share of electric home cooking	Share of electric home cooking will be 95% in 2050, compared to 5% gas cooking	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	Share of electric home cooking will be 100% in 2050

Table 2. Levers and ambition levels for Buildings - households.

		Lever	Description	1	2	3	4
Commercial heating, hot water and cooling	IX.c	**Commercial heating, hot water & cooling**					
		(i) Heating/Cooling	Demand for heating and cooling is determined by the growth in added value in the services sector	Demand is driven by the added value of the services sector that will increase on average with 2.3% until 2020 and with 1.8% between 2020-2050	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	Demand is driven by the added value of the services sector that will increase on average with 0.4% between 2010-2050
		(ii) Efficiency	Energy efficiency of the services sector computed as the "(a) heating and (b) cooling demand per unit of added value", which depends on the level of heating/cooling required and on the energy performance of the buildings	Heating demand/added value: same performance improvement of the envelope as assumed for the residential sector result in a 13% efficiency improvement compared to the level of 2010; Cooling demand/added value: today almost 66% of the floor space of offices has active cooling. In 2050, 90% of the offices will be actively cooled	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	Heating demand: same performance improvement of the envelope as assumed for the residential sector with a reduction of 85% of heat demand compared to the level of 2010; Cooling demand: the fraction of non-residential floor space with airco is reduced by 50% due to increase in the use of passive cooling systems. Nearly all new build airco is achieved through passive design measures, achieving a 90% reduction in cooling demand compared to the level of 2010
		(iii) Electrification level	Level of electrification of heating technologies based on heat pumps	20% of the installed heating devices in the stock will be heat pumps by 2050	40% of the installed heating devices in the stock will be heat pumps by 2050	60% of the installed heating devices in the stock will be heat pumps by 2050	85% of the installed heating devices in the stock will be heat pumps by 2050
		(iv) Alternative heating technology	Installation of alternative heating technologies: district heating with CHP/cogeneration or heat from power stations, micro-CHP, geothermal energy except from electric heating (heat pumps)	Alternative technologies represent 10% of the non-electric heating installations	Alternative technologies represent 20% of the non-electric heating installations	Alternative technologies represent 30% of the non-electric heating installations	Alternative technologies represent 40% of the non-electric heating installations
Commercial lighting and appliances	X.b	**Commercial lighting and appliances**					
		(i) Demand / Efficiency	Electricity demand for lighting & appliances per added value	Office Lighting: demand will stabilize at today's levels as efficiency levels continue to improve and the penetration of office lighting continues to increase Appliances: the electricity consumption for appliances will grow with 25% between 2010 and 2050, due to increased penetration	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	Office Lighting: demand for lighting per added value could halve by 2050 through eg. the increased use of LEDs and eg. through the use of motion detective lighting Appliances: through increasing adoption of more efficient technologies, electricity consumption is reduced by 25% by 2050
		(ii) Electrification of commercial cooking	Electrification pathway of commercial cooking	Commercial cooking: 85% will use electricity, compared to 15% natural gas	Commercial cooking: 100% will use electricity	/	/

Table 3. Levers and ambition levels for Buildings - services.

C.4 Industry

Context

Industrial production plays a vital role in the Belgian economy, representing about 23% of GDP (including construction) in 2010.[31] In addition, many activities in the tertiary sector provide auxiliary services for industry. Except for its coal (which at present is no longer economical to exploit), Belgium has limited natural resources. Industrial production thus has to rely on the import of raw and semi-manufactured materials. These materials are transformed into semi-finished and finished products which are mainly exported. Belgian industrial production thus depends heavily on intra-European (about 80% of trade) and worldwide trade (about 20% of trade). The high density and quality of the Belgian transportation network (ports, rivers, canals, highways, railroads etc.) play a crucial role in supporting these high import and export levels. Belgium hosts a variety of industrial activities, including refineries, production of steel, cement, lime, glass, chemicals and pharmaceuticals, pulp and paper, food processing, heavy machinery, non-ferrous metals, and ceramics. All of these sectors are modelled in detail in this study; an 'Other' category covering other industrial sectors is modelled in less detail.

Industry is one of the main energy consuming sectors in Belgium, representing 42% of the overall final demand for energy vectors in 2010 (including non-energetic uses). Over the period 1990-2010, industrial GHG emissions decreased faster than the average for the Belgian society: industrial GHG emissions decreased by 23% (see Figure 6) compared to 8% overall for the total of the Belgian economy. Industrial GHG emissions in 2010 accounted for a total of 37 $MtCO_2e$ (28% of the total for Belgium), originating from combustion of fossil fuels (24 $MtCO_2e$; 65% of industrial emissions) and industrial processes (13 $MtCO_2e$; 35% of industrial emissions). The good historical results have been achieved by a combination of efficiency gains, fuel switching (mainly from coal and fuel oil towards gas) and some loss of production (most notably in the steel sector, which is very carbon intensive).

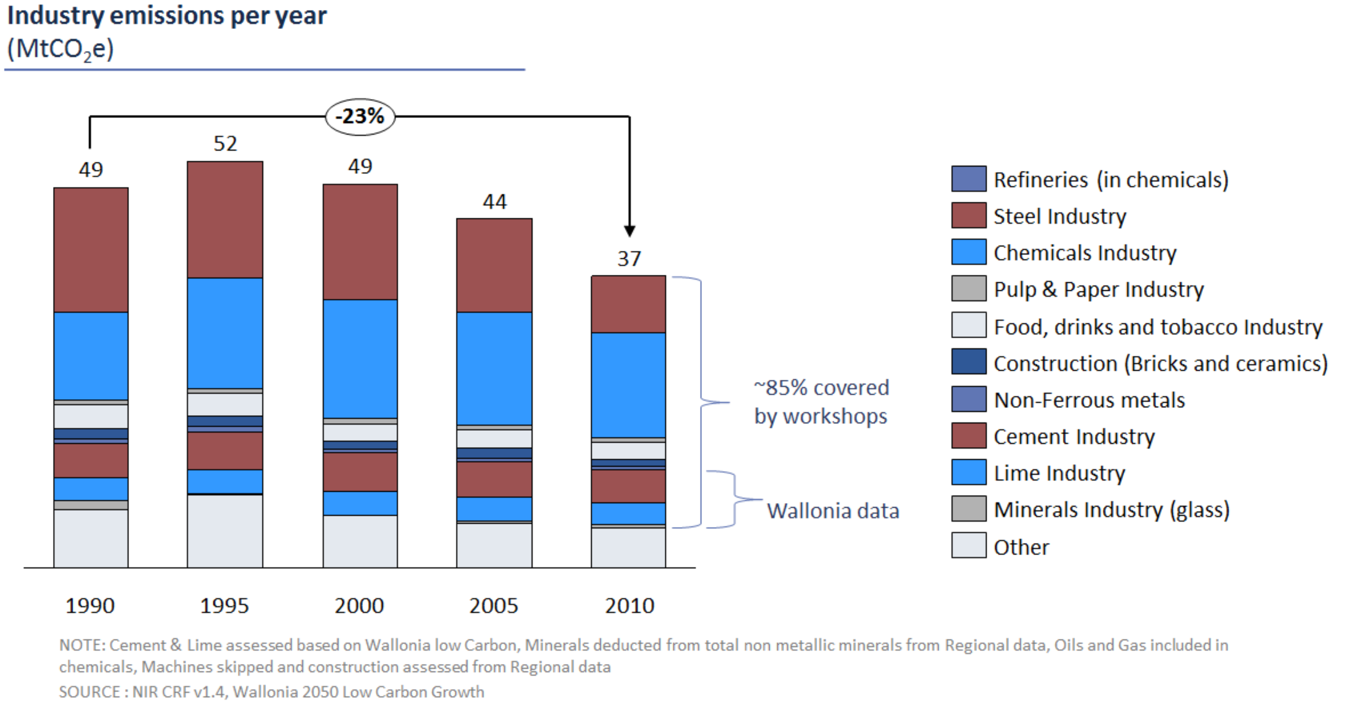

Figure 6. Industry, GHG emissions, evolution 1990-2010.

[31] Eurostat, http://epp.eurostat.ec.europa.eu/portal/page/portal/national_accounts/data/main_tables.

Scope for efficiency improvement remains in the majority of sectors in Belgium, but in some sectors substantial further reductions are likely to involve high levels of investment in new technologies, materials and processes.

The industry analysis models the various industrial sectors in Belgium. It has been performed based on an extensive literature review, work realised in previous studies[32] and numerous consultations with experts from the following sectoral federations: Refineries, Steel, Chemicals, Pulp & paper, Food, Ceramic, Non-Ferrous, Cement, Lime and Glass representing more than 85% of the GHG emissions in the industry[33].

Driving forces

The main driving force for industrial production in Belgium is of course the demand for Belgian industrial products in Belgium and on the world market. The main challenge for long-term Belgian climate policy will be to mitigate GHG emissions resulting from existing industrial production while still supporting industrial activity and to develop new low-carbon industrial activities because of its vital role in the Belgian economy. Climate policy will create new opportunities (new products and services) for some sectors (e.g. production of batteries for electric cars, production of insulation materials, etc.). However, other industrial sectors will inevitably see a decline in their production unless they convert to low-carbon alternatives. Refineries will experience a decline of fossil fuel outputs in a low-carbon future. This will also have an impact on the chemical sector relying on refinery by-products (naphtha) as feedstock as this change could for instance push the chemical industry towards the introduction of bio-based chemicals. In addition, while not necessarily reducing the economic output of the food processing sector (in terms of added value), a global shift towards less carbon-intensive eating habits (e.g. leaner diets, less consumption of meat) will reduce the physical output level (and hence GHG emissions) of the food processing industry. These changes have been taken into account in our scenario development.

Because of the uncertainty in the long-term economic outlooks for different industrial sectors, three 'trajectories' (representing a 'high', 'middle' and 'low' growth path for each industry) have been modelled. These trajectories allow us to explore industrial GHG emissions under a wide range of possible growth assumptions; they should not be interpreted as 'predictions of' or 'preferences for' growth/decrease in certain sectors. Neither should these trajectories be interpreted as policy levers: they represent possible evolutions in the production of the industrial sectors, not what policy could or should do to increase or reduce production levels in certain sectors.

For each industrial production trajectory, different technical measures for reducing GHG emissions have been modelled in the various interactions with the sectors. These generally fall into four categories:

- **energy efficiency measures**, allowing further GHG emission reductions of -5% to -40% depending on the sector and ambition level;
- **process improvements**, including a variety of sector-specific process changes designed specifically to reduce the carbon intensity of the process. Some examples include a shift to electro-steel or application of the Hisarna-technology in the steel sector; a shift to 'green chemistry' using biomass as an input for up to 25% of materials produced in the chemicals sector; a shift to black liquor gasification (combined with CCS) in the pulp & paper industry;

[32] Including Devogelaer, D., J. Duerinck, D. Gusbin, Y. Marenne, W. Nijs, M. Orsini and M. Pairon (2012), *Towards 100% renewable energy in Belgium in 2050*, mimeo, December and *'Vers une Wallonie bas-carbone en 2050'*, Climact 2012.

[33] As mentioned earlier, the responsibility of the analysis lies with the authors and the experts consulted do not necessarily endorse the analyses or the conclusions.

- **fuel switching**, allowing up to 100% GHG emission reductions (at the highest ambition level) from combustion of fuels for those sectors where it is technically feasible to replace fossil fuels by solid, liquid or gaseous biomass;[34]
- **application of carbon capture and storage (CCS)**, allowing GHG emission reductions of up to 85% depending on the specific sector. It must be mentioned the considerable debate surrounding CCS opportunities and risks. It is not the purpose of this study to balance these risks and opportunities and we considered CCS as a temporary solution to achieve GHG reductions rapidly. As developed below, 80% to 95% GHG reduction requires CCS unless we are highly ambitious on the behavioural levers.

European Emissions Trading System

The European emission trading system (ETS) and the price of carbon will continue to be a major driver towards low-carbon solutions for industry. The ETS cap now defined at EU level (-1.74% yearly) does not lead to 80-95% reduction in the EU and will need to be revised. The ETS carbon price can be one important instrument to activate the various levers in the industry. However, the link between any ambition level of each lever and a carbon price is not modelled, so there is no optimization of which levers are implemented based on such a carbon price. This is clearly one drawback of the accounting approach of the study and calls for prudence on the interpretation of the reduction percentages in the industry.

Investment strategies in the asset-intensive heavy industry generally depend on the cost of existing facilities and the complexity of operations. Core industrial processes change only gradually over the years and the investment cycles in heavy industry are long: in some sectors, 2050 is only one or two major investment opportunities away. Climate policy therefore needs to make clever use of the ‘window of opportunity’ offered by a new investment cycle while preventing carbon leakage: a delocalization of carbon-intensive industrial activities outside Belgium in other regions with less stringent climate policy regimes is detrimental to reaching global GHG emission reduction goals.

[34] This assumption has been made in order to be in line with the "100% renewable energy for Belgium" study.

Ambition levels for industry levers

	Lever or trajectory	Description	1	2	3	4
Steel	(i) Steel production evolution	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Growth of 0,46% per year (+20% by 2050). Oxi-steel is only produced in Arcelor Mittal Gent (with a maximum capacity of 5 Mton). Electro-steel is produced on all other sites	Stabilised production without growth	Reduction of 1,72% per year (-50 % by 2050)	
	(ii) Energy and carbon intensity of the production	Combination of product mix changes (electrosteel and higher processability steel), energy efficiency measures, new technologies (top gas recirculation and hisarna) and fuel switches (gas injection and Coke substitution by biomass)	Increase of electro-steel by 17% in 2050 vs 2010 (shifting Wallonia integrated steel production to electric)	Increase of electro-steel by 17% by 2050 vs 2010 (shifting Wallonia integrated steel production to electric), +13% shift to high processability steel, 5% improvement of overall energy efficiency in integrated steel production, introduction of Top Gas recirculation, resulting in 25 % savings of coke and coal, coal substitution at 2% by gas injection, coal PCI susbtitution at 15 % by biomass, CCS on oxygen steel (on top gas recirculation)	Increase of electro-steel by 17% by 2050 vs 2010 (shifting Wallonia integrated steel production to electric), +25% shift to high processability steel, 5% improvement of overall energy efficiency in integrated steel production, introduction of Hisarna technology (closing of coke and sinter plants and enabling +35% efficiency), coal substitution at 3% by gas injection, coal PCI substitution at 15% by biomass, CCS applies on all emissions sources in steel production	Shift of 100 % steel to electro steel production by 2050 vs 2010, +38% shift to high processability steel, 10 % improvement of overall energy efficiency, CCS applies on all emissions sources in steel production
Cement	(i) Cement production evolution	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Growth of +0.23% per year (+10% by 2050), supported by the building sector	Stabilised without growth	Reduction of -0.25% per year (-10% by 2050)	
	(ii) Energy and carbon intensity of the production	Measures of clinker substitution, energy efficiency and fuel switches (use of biomass)	Clinker substitution by steel slag reduces energy and process emissions by -15% by 2050 vs 2010, energy efficiency increases by +13%	Clinker subsitution by steel slag reduces energy and process emissions by -27% by 2050 vs 2010, energy efficiency increases by +17%, fuels substituted at 33% by solid biomass	Clinker substitution by steel slag reduces energy and process emissions by -53% by 2050 vs 2010, energy efficiency increases by +34%, fuels substituted at 66% by solid biomass	Clinker subsitution by steel slag reduces energy and process emissions by -85% by 2050 vs 2010, energy efficiency increases by +41%, fuels substituted at 100% by solid biomass
Lime	(i) Lime production evolution	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Growth of +0.1% per year (+5% by 2050), supported by demand for water purification, canal dredging and infrastructure demand	Stabilised without growth	Reduction of -0.8% per year (-30% by 2050), caused by the closure of the steel hot phase	
	(ii) Energy and carbon intensity of the production	Measures of energy efficiency and fuel switches (substitution of lignite by gas and use of biomass)	Energy efficiency increases by +13% by 2050 vs 2010	Energy efficiency increases by +23%, lignite is substituted at +33% by gas, fuels substituted at 10% by solid biomass	Energy efficiency increases by +30%, lignite is substituted at 66% by gas, fuels substituted at 20% by solid biomass	Energy efficiency increases by +36%, lignite is substituted at 100% by gas, fuels substituted at 30% by solid biomass
Glass	(i) Glass production evolution	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Growth of +1.7% per year (doubling by 2050), with hollow glass remaining stable	Stabilised without growth	Reduction of 0,4% per year (-16% by 2050), with hollow glass sector reduced by 50% by 2050 and flat afterwards and others glasses reduced by 10% by 2050	
	(ii) Energy and carbon intensity of the production	Measures of energy efficiency, process improvements (cullet increase & oxyfuels) and fuel switches (substitution by gas and biomass)	Energy efficiency increases by +8%	Energy efficiency increases by +15%, cullet use increases by +5%, oxyfuel use improves efficiency by +12%, fuel substituted at 100% by gas in 2050, fuels substituted at 3% by solid biomass	Energy efficiency increases by +30%, cullet use increases by +10%, oxyfuel use increases efficiency by +24%, fuel is substituted at 100% by gas in 2030, fuels are substituted at 6% by solid biomass	Energy efficiency increase by +36%, cullet use increases by +12%, oxyfuel use improves efficiency by +29%, fuel substituted at 100% by gas by 2020, fuels substituted at 7% by solid biomass
Chemicals	(i) Chemicals production evolution	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	An increase of 20 % for all activities under ETS and an increase of 40 % for activities not under ETS	A stabilistation of activities under ETS and an increase by 20 % of the activities not under ETS	A decrease by 50 % of all activities under ETS and a decrease by 20% of the activities not under ETS	
	(ii) Energy and carbon intensity of the production	Energy efficiency improvement, fuel switching, process improvements	Status quo	Penetration of 10 % green chemistry, replacing traditional plastics, 10 % energy efficiency gains for ETS activities, improvements in ammonia production process, CCS on ammonia and hydrogen production process emissions, replacing mercury cells by membrane cells, 80 % reduction of N2O emissions	Penetration of 20 % green chemistry, replacing traditional plastics, 0 to 30 % energy efficiency gains, CCS on all installations > 1 Mton, but not on crackers, 90 % reduction of N2O emissions	Penetration of 50 % green chemistry, replacing traditional plastics, 30 to 40 % energy efficiency gains, CCS on installations > 200 kton, including crackers, 95 % reduction of N2O emissions

Table 4. Levers and ambition levels for Industry (1/2).

	Lever	Description	1	2	3	4
Pulp & paper industry	(i) Pulp & paper production evolution	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Growth of +1.2% per year (+61% by 2050)	Stabilised without growth	Reduction of -0.8% per year (-27% by 2050)	
	(ii) Energy and carbon intensity of the production	Energy efficiency measures, fuel switch (substitution of liquid fuels by gas, switch to biomass in Kraft pulp mills)	Energy efficiency increases by +10%	Energy efficiency increases by +15%, liquid fuels substituted by gas, solid fuels substituted at 70% by biomass in Kraft pulp mill	Energy efficiency increases by +20%, all liquid fuels substituted by gas, solid fuels substituted at 85% by biomass in Kraft pulp mill	Energy efficiency increases by +25% all liquid fuels substituted by gas, solid fuels substituted at 95% by biomass in Kraft pulp mill
Oil & gas industry - Refineries	(i) Evolution of production of total final products (kton product)	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Reduction of -0.2% per year (-8% production by 2050); related to reference trajectory from 100% RES study taking into account only 202020 goals of energy-climate package	Reduction of at least -0.9% per year (-30% by 2050); but decrease will be hardlinked with the demand from other sectors	Reduction of -1.7% per year (-50% by 2050); but decrease will be hardlinked with the demand from other sectors	Correlation to the evolution of fuel demand in the other sectors: will vary significantly between the different scenarios
	(ii) Energy and carbon intensity of the production	Energy efficiency measures, fuel switch (susbstitution of liquid fuels by gas), process improvements for specific units with high energy use and emissions (crude destillation unit, fluidised catalytic cracker, flare gas, desulpherisation unit)	Energy efficiency increases by +10%	Energy efficiency increases by +18%, 10% extra implementation of CHP, fuel substituted at 25% by natural gas	Energy efficiency increases by +30%, 15% extra implementation of CHP, fuel substituted at 50% by natural gas, process improvement applied starting from 2030 reaching 15% reduction energy use	Energy efficiency increases by +50%, 20% extra implementation of CHP, fuel substituted at 100% by natural gas, process improvements applied starting from 2020 reaching 23% reduction energy use
Food & drinks industry	(i) Food & drinks production evolution	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Growth of +2% per year (+120% by 2050)	Growth of +1.3% per year (+68% by 2050)	Stabilised without growth	Correlation to the evolution of fuel demand in the other sectors: will vary significantly between the different scenarios
	(ii) Energy and carbon intensity of the production	Energy efficiency measures, fuel switch: substitution of solid & liquid fuels by gas, substitution of gas by biogas	Energy efficiency increases by +10%	Energy efficiency increases by +20%, all solid and liquid fuels subsituted by gas	Energy efficiency increased by +30%, all solid and liquid fuels switched to gas, gas substituted at 50% by biogas	Energy efficiency increases by +40%, all solid and liquid fuels substituted by gas, gas substituted at 90% by biogas
Non-ferrous metals industry	(i) Non-ferrous metals production evolution	2 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Growth of +0.8% per year (+30% by 2050)	Stabilised production without growth		
	(ii) Energy and carbon intensity of the production	Energy efficiency measures, fuel switch (substitution of liquid fuels by gas, substitution of gas by biogas), electrification	Energy efficiency increases by +5%	Energy efficiency increases by +10%, all liquid fuels substituted by gas, gas substituted at 25% by biogas	Energy efficiency increases by +20%, all liquid fuels substituted by gas, gas substituted at 50% by biogas	Energy efficiency increases by +30%, all liquid fuels substituted by gas, gas substituted at 90% by biogas, half of the furnaces are switched to electric
Ceramics industry	(i) Ceramics production evolution	3 potential production trajectories between 2010 and 2050 (ktons). This is used as a potential evolution not as a lever	Growth of +3.5% per year between 2015-2025; stable after 2025 (+68% by 2050)	Growth of +2.5% between 2015-2025; stable after 2025 (+44% by 2050)	Growth of +3.7%/year between 2015-2015; stable after 2015 (+20% by 2050)	
	(ii) Energy and carbon intensity of the production	Energy efficiency measures, fuel switch (substitution of solid & liquid fuels by gas, substitution of gas by biogas)	Energy efficiency increases by +10%	Energy efficiency increases by +20%, all solid and liquid fuels susbsituted by gas, gas subsituted at 25% by biogas	Energy efficiency increases by +30%, all solid and liquid fuels substituted by gas, gas substituted at 50% by biogas	Energy efficiency increases by +40%, all solid and liquid fuels substituted by gas, all gas substituted by biogas
Industrial processes	(iii) Industrial Carbon Capture & Storage	Deployment of CCS technologies on industrial sites, enabling the Carbon Capture and Storage either underground either offshore (e.g. off the Dutch coast)	No development	All the installations producing above 1 MtCO2e/year are equiped of CCS and their residual emissions are reduced by 85%	All the installation producing above 300ktCO2e/year are equiped of CCS and their residual emissions are reduced by 85%	All the industrial installations of the industrial sectors above and producing significant GES emissions are equiped, enabling to reduce residual emissions by ~85% For Pulp&Paper, when CCS is applied, black liquor gasification is applied as well

Table 5. Levers and ambition levels for Industry (2/2).

C.5 Agriculture & Waste

Context

Although agriculture represented only 0.6% of GDP in 2010, the sector has an important share in Belgian exports, namely 5.7%.[35] Belgium is a net exporter for most meat and dairy products. For instance, the degree of self-supply of meat is ~170%.[36]

The agriculture sector has GHG emissions of a completely different nature from the other sectors, with significant non-combustion and non-CO_2 emissions directly produced by the animals themselves (enteric fermentation, CH_4), or by nitrate fertilizers converted to nitrous oxide (N_2O). These sources of GHG are technically very difficult to reduce without simply reducing the demand for the products.

Currently, there are regional differences in livestock and dynamics of land used for agriculture. Agricultural land is relatively evenly split between Flanders and Wallonia. However, increased competition for land is expected to have a larger impact in (densely populated) Flanders in the short and medium term than in Wallonia. Livestock numbers is much larger in Flanders, with >80% of animals. Brussels capital region has almost no agricultural activity. Evolution of agriculture in Belgium is directly related to the Common Agricultural Policy of the European Union.

We focused on following sources of CH_4 and N_2O emissions: enteric fermentation, manure management and agricultural soils. The latter focuses only on direct N_2O emissions (e.g. applied fertilizers, mineralization of organic soil, organic matter and crop residues) and N_2O emissions of grazing animals. The agricultural sources of N_2O and CH_4-emissions are not the main sources of GHG emissions in Belgium. Nevertheless reduction of these emissions is fundamental in reaching the 80% to 95% reduction in GHG by 2050. The burden on the other GHG emitting sectors increases if no or limited emission reduction efforts are made by the agricultural sector.

In 2010 the non-combustion emissions of agriculture in Belgium amounted to 10 MtCO2e.[37] Almost 40% of these emissions originated from N_2O emissions from soil. As enteric fermentation and agricultural soils are concerned, Wallonia and Flanders represented an equal share in GHG-emissions. As manure management is concerned, Flanders represented a share of ca. 78% of total CO_2 equivalents. N_2O and CH_4 emissions of agriculture in Belgium decreased with ca. 14% in the period 1990 – 2010. CH_4 emissions from enteric fermentation decreased due to general livestock reduction and the shift from dairy cows to brood cows (lower emissions), i.e. general EU trend linked to the Common Agriculture Policy. CH_4 and N_2O emissions related to manure management decreased due to a decline of swine livestock. N_2O emissions from soils decreased due to smaller quantities of nitrogen from mineral fertiliser applied and livestock reduction (reduction of nitrogen excreted on pasture).

N_2O and CH_4 emissions originating from agriculture in Belgium decreased with ~ 14% in the period 1990 – 2010. If no additional measures are taken, emissions will increase with ca. +6% in 2050 compared to 2010. Significant reductions (~ 46%) can be achieved by changing consumer behaviour (53% reduction of meat consumption) and additional abatement measures, as highlighted below.

[35] FOD Economie, Middenstand, KMO en Energie, Kerncijfers Landbouw, 2011.
[36] http://www.vlam.be/facts/.
[37] Belgium's greenhouse gas inventory 1990-2010.

Driving forces

The **main drivers** of the non-combustion emissions are the amount of livestock and growth perspectives, yields of the various crops, amount of nitrogen excreted per animal, volatile solids excreted per animal and nitrogen input to soils. Options to reduce CH_4 emissions from enteric fermentation are based on the reduction of the amount of livestock, productivity increase (decrease of CH_4 per unit of product) and improvement of rumen efficiency and feed conversion efficiency. Options to reduce CH_4 and N_2O emissions from manure management are related to livestock reduction, amount and characteristics of manure, animal waste management. Options to reduce direct N_2O emissions of agricultural soils are related to controls of nitrification and denitrification, soil and crop management.

We modelled the evolution of the number of animals, evolution of CO_2-equivalents per animal related to enteric fermentation and manure management, and the evolution of total soil emissions.

Number of animals: reduction of meat consumption with 53% between 2010-2050 can reduce enteric emissions with 43% (with increased demographics); this reduction of meat consumption is based on a healthy and balanced diet of 75 grams of meat per day per capita. A shift towards a healthier and balanced diet implies eating more vegetables and fruit, eating less meat and exercises more. We focus on the consumption of meat as changes have a direct impact on the greenhouse gas emissions we deal with in this study. The national food plan indicates that a healthy diet consists of 75 to 100 grams of meat, fish, eggs (and meat substitutes) per day per capita.[38]

We modelled this change in consumer behaviour implicitly by “translating” it into changes in numbers of animals (% reduction is equal for all animal categories). We assume that in the countries that import Belgian meat, less meat will also be consumed and the drop in consumption will follow the same pace as in Belgium.

Enteric fermentation: if no additional measures are taken enteric emissions will increase by 11% in 2050 compared to 2010, due to increase in livestock. Emissions can be reduced by 44% in 2050 compared to 2010 by a 43% decrease in livestock and complementary abatement options (such as non-specific CH_4 inhibitors, combined with nutritional management and optimizing ration).

Manure management: if no additional measures are taken emissions related to manure management will increase by 7% in 2050 in comparison to 2010 due to increase of livestock and rise in productivity. Emissions can be reduced by 37% in 2050 in comparison to 2010 by increasing production efficiency, increasing the manure treated in anaerobic digesters and good manure management practices.

Soil emissions: no additional abatement measures were introduced; direct emissions will decrease by 3% in 2050 compared to 2010, due to N-efficiency improvement that reduces the amount of N put to soil; emissions that originate during grazing of animals decrease by 40% in 2050 compared to 2010 due to decrease of N excreted.

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[38] http://www.belgium.be/nl/gezondheid/gezond_leven/voeding/nationaal_plan.

Ambition levels for Agriculture levers

	Lever	Description	1	2	3	4
Indigenous production	**Agriculture and livestock**					
	(i) Number of animals and meat consumption	Evolution of the number of animals, based on a direct impact from demography and changes in diets/meat consumption in Belgium	With an increasing population and similar diets, the meat consumption increases and results in an increase in the number of animals by 2% in 2050 compared to 2010 this leads to ~43 mio animals in Belgium in 2050	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	Changes in the diets lead to a decrease in meat consumption, and a resulting decrease in the number of animals by 43% in 2050 compared to 2010 this leads to ~ 24 mio animals in 2050
	(ii) Emissions intensity per animal (enteric fermentation)	Ruminants produce methane through digestion. Various measures look at how to reduce these emissions per animal	Stabilization of methane emissions per animal to today's levels	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	Various reduction measures such as nutritional management and optimizing ration per animal lead to a reduction in the emissions per animal of -0,06% per year from 2010 to 2030, followed by a stabilization up to 2050
	(iii) Emissions intensity per animal (manure management)	The way animal manure is being stocked and treated can lead to significant amount of methane emissions. Various measures look at how to reduce these emissions	Increase in the emissions of manure per animal of 0,31% per year from 2010 to 2030, followed by a stabilization of the emissions per animal up to 2050 due to an increase in productivity	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	Production efficiency reduces the amount of animals required to produce the same amount of meat. Along with that, a larger share of manure is treated in anaerobic digesters and good manure management practices increase
	(iv) Evolution of soil emissions	Evolution of total Nitrous oxyde (N2O) emissions in the agriculture sector based on - direct N2O emissions from e.g. applied fertilizers (manure, artificial), mineralisation of organic soil, organic matter and crop residues, - direct N2O emissions from grazing animals, - and indirect N2O emissions e.g. through leaching, runoff or atmospheric deposition	Overall stabilization of direct N2O emissions as the impact of an increase of N input to agricultural soils is offset by a decrease of ha agricultural land. The emissions from grazing increase as nitrogen excretions per animal increase due to improved nutrition in support of productivity growth	Intermediary level between levels 1 and 4	Intermediary level between levels 1 and 4	Improvements in the use and the efficiency of nitrogen reduce the amount of N input to the soil and reduce direct emissions. Additionally, the decrease in the nitrogen excreted also reduce emissions from grazing. This leads to a reduction in the overall emissions on agricultural soils of -0,66% per year up to 2030, and a stabilization thereafter up to 2050
	(v) Belgian indigenous biomass production	Evolution of the exploitation of biomass and maximum technical indigenous potential. The focus is on biomass collection from forests as well as on a variety of biogas streams. Biomass for energy is always assumed secondary to food and direct uses, and there is no assumption of changes in soil affectation	The biomass potential is exploited to reach Belgian objectives of 13% RES in final energy demand by 2020. Exploitation then increases progressively to reach 100% of the potential identified by Valbiom in Wallonia, and Ovam in Flanders in 2050 (altogether ~27 TWh of biomass and biogas)	100% of the biomass potential identified by Valbiom in Wallonia, and Ovam in Flanders is exploited in 2020 (altogether ~27 TWh of biomass and biogas) and stays stable after that	100% of the biomass potential identified by Valbiom in Wallonia, and Ovam in Flanders is exploited in 2020 (altogether ~27 TWh of biomass and biogas) and stays stable after that. The biogas production increases progressively to reach the full potential identified by Edora in Wallonia en 2050 (~3 to ~9 TWh, bringing total potential to 36 TWh)	100% of the biomass potential identified by Valbiom and Edora in Wallonia, and Ovam in Flanders is exploited in 2020 (~33 TWh of biomass and biogas). Production continues to increase slightly over time with improved efficiency, reaching 30% more in 2050 (~45 TWh)
	Waste volume and recycling	CO2, CH4 and N2O GHG emissions from waste management were of 1,3 MtCO2e in 2010	GHG Stabilization at current level	Linear decrease of 50% to reach 0,6 MtCO2e in 2050	Linear decrease of 75% to reach 0,3 MtCO2e in 2050	Linear decrease to reach 0 MtCO2e in 2050
	Marine algae [UNUSED]					
Imports	**Imports of bioenergy (solid biomass and biogas)**	Evolution of solid and gaseous bioenergy imports starting from ~14 TWh in 2010	Gradual increase of the import level to 20 TWh/year in 2020 and then to ~30 TWh/year in 2050	Gradual increase of the import level to 20 TWh/year in 2020 and then to ~38 TWh/year in 2050	Gradual increase of the import level to 20 TWh/year in 2020 and then to ~47 TWh/year in 2050	Gradual increase of the import level to 20 TWh/year in 2020 and then to ~56 TWh/year in 2050
	Imports of biofuels (liquid biomass)	Evolution of liquid bioenergy imports starting from ~5 TWh in 2010 (mostly produced in Belgium). This potential is included in the maximum 110 TWh above	Gradual increase of the import level to the 10,14% from the NREAP leading to ~7 TWh in 2020 and then stabilization to 2050	Gradual increase of the import level to the 10,14% from the NREAP leading to ~7 TWh in 2020 and then gradual increase to ~10 TWh by 2050	Gradual increase of the import level to the 10,14% from the NREAP leading to ~7 TWh in 2020 and then gradual increase to ~12 TWh by 2050	Gradual increase of the import level to the 10,14% from the NREAP leading to ~7 TWh in 2020 and then gradual increase to ~14 TWh by 2050

Table 6. Levers and Ambition levels for the Agriculture sector.

C.6 Energy supply

Context

Our well-being, the competitiveness of our industries, and the overall functioning of our societies are dependent on energy. It is essential to continue finding the right sources of energy to ensure that this supply is sustainable but also sufficiently secure and affordable, as it must continue supporting our societal structures and avoid carbon leakage to countries with lower energy costs.

The energy sector is clearly one of the sectors where long term planning is essential. The energy infrastructures that will be needed to power our homes, industry and services in 2050 are already starting to be built today. The transition towards a new energy system has begun. It needs to be steered in the right direction.

Figure 7 illustrates historical final energy consumption in Belgium which has remained relatively stable over the past 10 years, around 520 TWh. At the sector level, Transport experienced a slight increase, Buildings remained relatively stable and Industry decreased slightly.

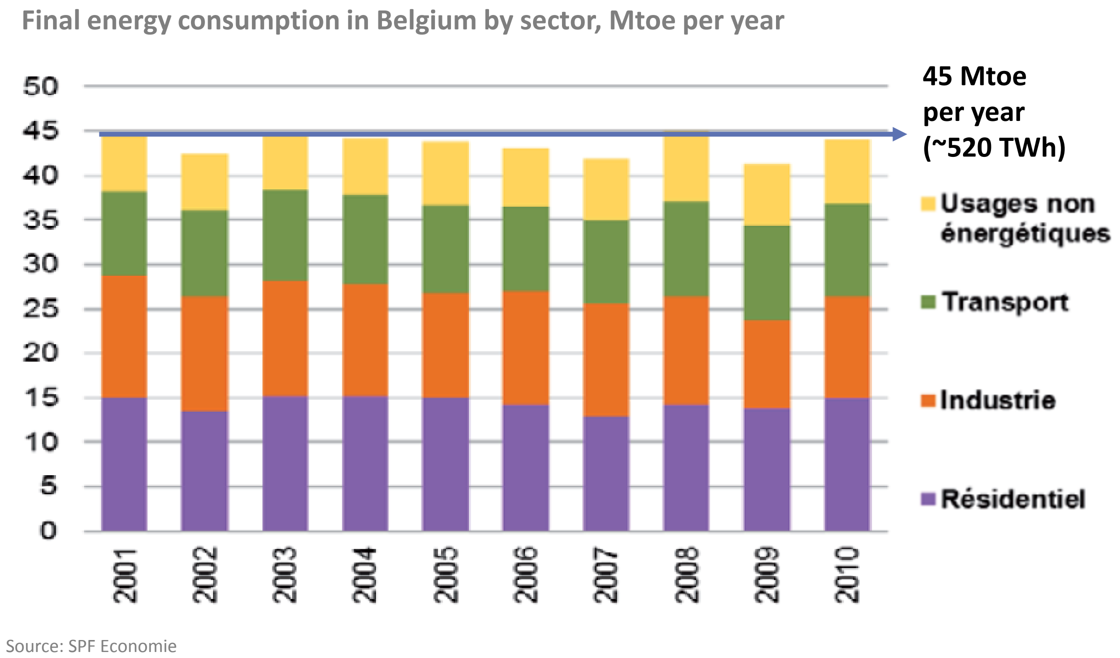

Figure 7. Final energy consumption in Belgium.

Figure 8 shows the share by energy vector in Belgium in 2010, with electricity representing 16% of final energy demand. The share of electricity within the energy mix is expected to increase along with decarbonisation.

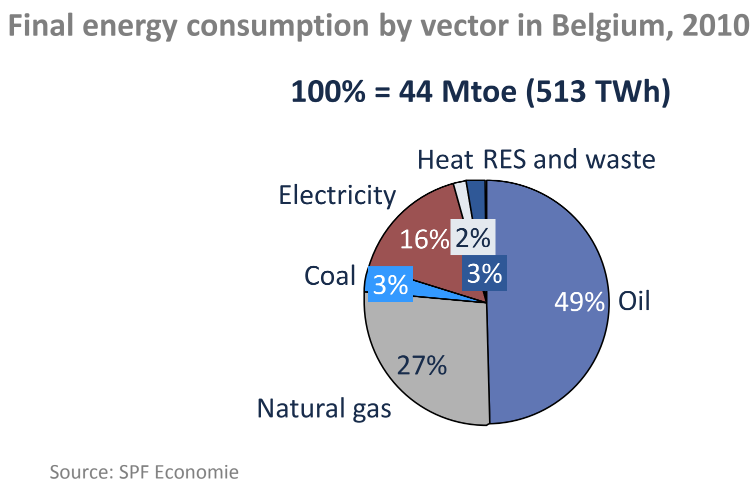

Figure 8. Final energy consumption by vector.

Electricity production in 2010 (Figure 9) relied on nuclear for ~50% of the yearly output. Fossil fuels were also significant contributors, with mostly gas and some remaining coal power plants covering another ~40%. Renewable Energy Sources (RES), waste and hydro pumping made up the remaining ~10% of energy used to produce electricity.

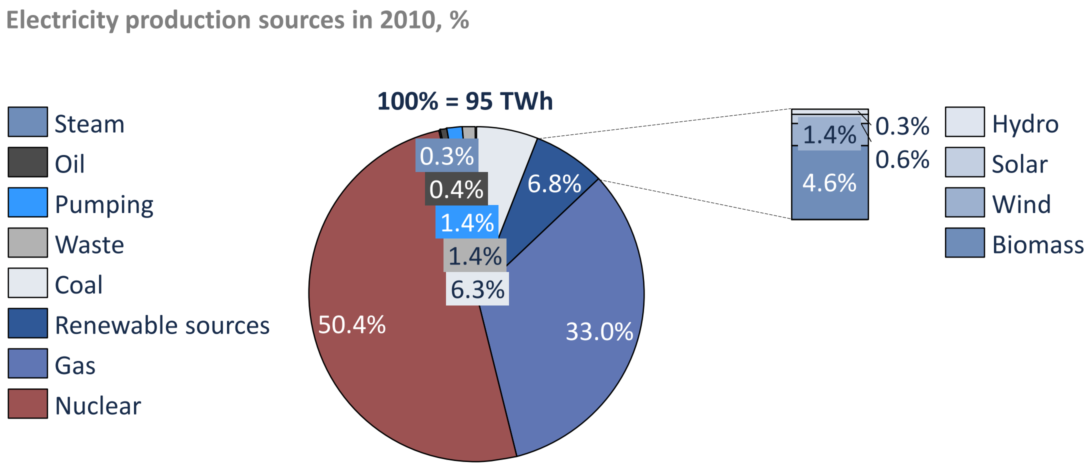

Figure 9. Belgian 2010 Electricity production mix.

The electricity production sector has a strong European dimension. It is essential to leverage the strengths and synergies between member states to share the required efforts, minimize redundancies and guarantee a minimal cost to society. A coherent strategy must combine the practical implementation at the member state level with vision and implementation on a European scale. This is why the results of the Roadmap 2050 and Power Perspectives 2030 studies funded by ECF,[39] were integrated in our analysis. Their study models the impact of complete decarbonisation of the electricity production sector, and optimizes the transmission and back-up requirements at the European level.[40]

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[39] "Roadmap 2050" and "Power Perspectives 2030: on the road to a decarbonised power sector", McKinsey, KEMA, Imperial College London.

[40] The methodology and the main assumptions of the these European studies are public and can be found on the following website: http://www.roadmap2050.eu/.

Driving forces

Energy demand is logically the central driving force for energy supply. The OPEERA model is an accounting model which ensures that the resulting total energy demand from all demand sectors is properly supplied.

Each source of potential energy supply has been analysed in detail to define the right level of potential deployment. These ambition levels have been presented as four levels of potential roll-out of energy supply infrastructure (levels 1–4), representing increasing levels of effort. The levels depend on the lead time and build rate of new energy infrastructure, and different assumptions about how quickly and on what scale the infrastructure can be rolled out. The higher levels also depend on improvements in technology, such as floating wind turbines and carbon capture and storage. The build rates will in practice depend not only on the physical possibilities, but also on investment decisions by the companies involved, as well as wider international developments and public acceptance.

As described above, the energy supply mix in each scenario is not optimized based on costs (although the resulting impact on costs is estimated) but is based on the choices made by the model user, who defines a specific energy mix based on the available potential of each technology.

The study takes place in the context of the 2003 law on the nuclear exit[41] and stays in line with the law and the current policy, taking account of legal provisions.

Biomass potential and allocation

Biomass resources can be derived from a wide variety of sources. Biomass is a flexible resource, however limited, and the precise level of its future availability is uncertain.

There is likely to be further competition for biomass resources globally and from a number of sectors such as food and paper. This study considers biomass for energy always as secondary to food and direct uses.

Bioenergy will be important to achieving the GHG emissions target. Utilisation of both domestically produced and imported bioenergy will require careful monitoring of many impacts, including the impacts of direct and indirect land use change, the effects on local livelihoods and natural ecosystems and the impacts on global food prices. Including sustainability criteria in the assessment of biomass potential for energy is therefore of crucial importance. This debate is quite complex mainly due to the multiplicity of bioenergy sources and the involvement of various stakeholders.

Even with the use of sustainability criteria, the potential of worldwide available bioenergy varies significantly. The level of maximum imports used in this work is based on the estimated maximum sustainable amount of biomass production worldwide. Various studies[42] analyse this potential of biomass at different geographical levels and timeframes.[43] Estimates of biomass potential in 2050 vary by a factor of almost 50,[44] due to significant uncertainties

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[41] See Law of 31 January 2003 on the Phase-out of Nuclear Energy for the Purpose of the Industrial Production of Electricity.

[42] Main studies consulted are IPCC SRREN Special Report on Renewable Energy Sources and Climate Change Mitigation, Bioenergy by H. Chum, A. Faaij and J. Morerira, The contribution of biomass in the future global energy supply: a review of 17 studies by G. Berndes, M. Hoogwijk , R. van den Broek, EEA 2007, TB. Larsson, Environmentally compatible bio-energy potential and Biomass for heat and power: opportunity and economics, European Climate Foundation.

[43] Most of these studies have been assessed in the 'Biomass Energy Europe, Illustration case for Europe', 2010, International Institute for Applied Systems Analysis, B. Koch, M. Dees & al.

[44] See 'The global technical potential of bio-energy in 2050 considering sustainability criteria', 2010, H. Haberl, T. Beringer, S. Bhattacharya, K-H. Erb and M. Hoogwijk and 'Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios', 2005, M. Hoogwijk, A. Faaij, B. Eickhout, B. de Vries, W. Turkenburg.

remaining, such as level of competition for food and paper, availability of land, potential of yield crops, impact on biodiversity and water, climate impacts, etc.

We use as reference the potential identified in the Haberl study and confirmed in the Beringer work,[45] suggesting a yearly global potential in 2050 between 160 and 270 EJ (vs. 50 EJ per year today). This potential is then distributed equally per person at the world level. This leads to 80 to 100 TWh of potential for Belgium (including ~34 TWh of indigenous production).

This work does not attempt to define the optimal allocation of biomass across sectors, which would require more extensive analysis. The model therefore assumes a reduction of the combined demand for fossil fuels from the different sectors based on the overall biomass potential that can be used for energy purposes by type (solid, gaseous or liquid). However, it is important to know the amount of non-intermittent (including biomass) and intermittent electricity supply in the mix to estimate grid extensions and back-up implications. Therefore, the model requires that the user define the level of biomass used for power production. The rest of the biomass potential goes to the industry and building sectors based on their maximum substitution levels.

[45] 'Bioenergy production potential of global biomass plantations under environmental and agricultural constraints', T. Beringer, W. Lucht, S. Schaphoff, 2011. The 100% RES study in Belgium has based its work on the same assumption.

Ambition levels for Energy levers

Supply			Lever or trajectory	Description	1	2	3	4
Energy prices			**Evolution of international fossil fuel energy prices**	Evolution of energy prices compared to 2010, these trajectories are based on the latest IEA ETP 2012 publication, which shows similar trends to the Energy 2050 Roadmap of the EU commission, the evolution of the price of biomass based on global market, both imported and indigenous biomass are assumed to be sold on the same markets	Based on the IEA 2DS, the scenario which limits the increase in average global temperatures to 2°C, and where fossil fuel prices stay lowest due to lower global energy demand: - oil prices increase from ~80 USD/bbl in 2010 to ~ 100 in 2030, to come down again to ~90 in 2050; - gas prices increase from ~7 USD/mmBTU to ~10 in 2030, to come down again to ~8 in 2050; - coal prices come down from ~100 USD/tonne to ~75 in 2030, and 60 in 2050; - biomass prices reach highest price level because strong decarbonization policies lead to biomass demand increases. Biomass price goes from 88 $/boe in 2020 to 155 in 2050	Based on the IEA 4DS, the scenario where the increase in average global temperatures reaches 4°C: - oil prices increase from ~80 USD/bbl in 2010 to ~115 in 2030 and stabilize at ~120 in 2050; - gas prices increase from ~7 USD/mmBTU to ~12 in 2030 and stabilize there up to 2050; - coal prices increase from ~100 USD/tonne to ~110 in 2030, and stabilize there up to 2050; - biomass follows a linear interpolation between level 1 and level 4	Based on the IEA 6DS, which effectively serves as IEA baseline scenario, and reflects a world where little is done to curb emissions and where the increase in average global temperatures reaches 6°C. It is line with the WWF 2050 Base case scenario: - oil prices increase from ~80 USD/bbl in 2010 to ~135 in 2030 and stabilize at ~150 in 2050; - gas prices increase from ~7 USD/mmBTU to ~13 in 2030 and further to 14 by 2050; - coal prices increase from ~100 USD/tonne to ~115 in 2030, and further to 125 in 2050; - biomass follows a linear interpolation between level 1 and level 4	Highest energy demand scenario, reflecting a world where fossil fuel demand increases the highest, with oil prices being most affected: - oil prices increase from ~80 USD/bbl in 2010 to ~170 in 2030 and stabilize at ~200 in 2050; - gas prices increase from ~7 USD/mmBTU to ~16 in 2030 and further to 20 by 2050; - coal prices increase from ~100 USD/tonne to ~130 in 2030, and further to 150 in 2050; - biomass prices decrease to lowest price level as weak decarbonization policies lead biomass demand not to increase significantly. Biomass price goes from 54 $/boe in 2020 to 78 in 2050
Electricity	**Indigenous production**	III.a.1	**Onshore wind**	Onshore wind capacity developed up to 2050, and resulting yearly installation rate (including replacements after 25 years)	Capacity increases up to ~7 GW in 2050, doubling the 3 GW capacity planned in 2020 in the Belgian NREAP. This requires installing 260 MW, or ~100 new turbines per year	Capacity increases up to ~8,5 GW in 2050. This requires installing on average 300 MW, or ~120 new turbines per year	Capacity increases up to ~10,5 GW in 2050. This requires installing on average 380 MW, or ~150 new turbines per year	Capacity increases up to maximum technical potential of ~13 GW in 2050. This requires installing on average 460 MW, or ~180 new turbines per year
		III.a.2	**Offshore wind**	Offshore wind capacity developed up to 2050, and resulting yearly installation rate (including replacements after 25 years)	Capacity increases up to 2 GW in 2020 (the NREAP goes to 1,3 GW) and ~4 GW in 2050. This requires installing 120 MW, or ~20 new turbines per year	Capacity increases up to ~7 GW in 2050. This requires installing on average 250 MW, or ~40 new turbines per year	Capacity increases up to ~10,6 GW in 2050. This requires installing on average 380 MW, or ~65 new turbines per year	Capacity increases up to maximum technical potential of ~16,5 GW in 2050. This requires installing on average 600 MW, or ~100 new turbines per year
		IV.a	**Solar PV**	Solar PV capacity installed by 2050, and resulting yearly installation rate (including replacements at the end of their lifetime progressing from 25 years today to 40 years in 2050)	Solar PV capacity reaches 2,5 GW in 2020 (higher than the 1,3 of the NREAP which has already been surpassed in 2012) and ~7 GW in 2050, or ~9% of 2010 Belgian electricity production. This requires annual growth to decrease to +~150 MW/year up to 2020, and then slowly increases back to +~400 MW/year in 2050 (average of 250 MW/year over the 40 years)	Annual growth decreases to +~200 MW/year up to 2020, and then slowly increases to +~1500 MW/year in 2050 (average of 600 MW/year over the 40 years). Solar PV capacity reaches ~21 GW in 2050, or ~28% of 2010 Belgian electricity production	Annual growth decreases to +~300 MW/year up to 2020, and then slowly increases to +~2700 MW/year in 2050 (average of 1000 MW/year over the 40 years). Solar PV capacity reaches ~35 GW in 2050, or ~47% of 2010 Belgian electricity production	Annual growth stays stable at ~430 MW/year up to 2020, and then slowly increases to +~3800 MW/year in 2050 (average of 1400 MW/year over the 40 years). Solar PV capacity reaches ~50 GW in 2050, or ~65% of 2010 Belgian electricity production
		III.b	**Hydroelectricity**	Installed hydroelectric capacity	110 MW, or no new installations by 2050	Gradual increase of 10 MW by 2050, reaching 120 MW	Gradual increase of 30 MW up to 2050, reaching 140 MW	Gradual increase of 40 MW reaching 150 MW by 2050
		III.d	**Geothermal**	Total installed capacity of geothermal electricity production, conventional or enhanced	Limited developments in conventional geothermal production due to limited potential. No enhanced production take place	Limited developments in conventional geothermal production due to limited potential. Gradual implementation of enhanced geothermal, with 60 MW in 2025, increasing up to 1 GW of installed capacity in 2050	Limited developments in conventional geothermal production due to limited potential. Gradual implementation of enhanced geothermal, with 200 MW in 2025, rapidly ramping up to reach 3 GW of installed capacity in 2050	Limited developments in conventional geothermal production due to limited potential. Gradual implementation of enhanced geothermal, with 500 MW in 2025, rapidly ramping up to reach 6 GW of installed capacity in 2050
		IV.b	**Solar Thermal**	Area covered with thermal solar panels for the production of residential hot water requirements	No significant development	Gradual increase up to an average of 1m² per household in 2050, which would require about 2% of roof space identified as available in Belgium	Gradual increase up to an average of 3m² per household in 2050, which would require about 7% of roof space identified as available in Belgium	Gradual increase up to an average of 5m² per household in 2050, which would require about 12% of roof space identified as available in Belgium
		II.a	**Nuclear trajectory**	The evolution of nuclear capacity as per latest federal plans (plan Wathelet) is used as the one trajectory across scenarios	Nuclear exit as per the latest official plans (plan Wathelet): shut down Doel 1 & 2 (0,4 GW each) in the spring of 2016, shut down of Doel 3 (1 GW) in 2022, closing of Tihange 2 (1 GW) in 2023, closing of Tihange 1 &3 and Doel 4 (1 GW each) in 2025	Nuclear exit as per the latest official plans (plan Wathelet): shut down Doel 1 & 2 (0,4 GW each) in the spring of 2016, shut down of Doel 3 (1 GW) in 2022, closing of Tihange 2 (1 GW) in 2023, closing of Tihange 1 &3 and Doel 4 (1 GW each) in 2025	Nuclear exit as per the latest official plans (plan Wathelet): shut down Doel 1 & 2 (0,4 GW each) in the spring of 2016, shut down of Doel 3 (1 GW) in 2022, closing of Tihange 2 (1 GW) in 2023, closing of Tihange 1 &3 and Doel 4 (1 GW each) in 2025	Nuclear exit as per the latest official plans (plan Wathelet): shut down Doel 1 & 2 (0,4 GW each) in the spring of 2016, shut down of Doel 3 (1 GW) in 2022, closing of Tihange 2 (1 GW) in 2023, closing of Tihange 1 &3 and Doel 4 (1 GW each) in 2025
		I.b	**Carbon Capture and Storage**					
			(i) Power plant capacity	Electric production capacity by power plants equiped with carbon capture, with subsequent transport and storage either in Belgium's underground, or offshore (e.g., old gas fields in the North Sea)	No CCS development	Construction of 1,1 GW of CCS capacity after 2030 (which would represent ~2 coal plants, or ~3 gas plants). This would cover ~10% of current electricity demand	Construction of 2,2 GW of CCS capacity starting in 2025 (which would represent ~4 coal plants, or ~6 gas plants). This would cover ~20% of current electricity demand	Construction of 4,4 GW of CCS capacity starting in 2020 (which would represent ~8 coal plants, or ~12 gas plants). This would cover ~40% of current electricity demand
			(ii) Fuel mix	Fuel mix between coal and gas used in the CCS plants	100% of the CCS capacity is coal based	2/3 Coal CCS and 1/3 gas CCS	1/3 Coal CCS and 2/3 gas CCS	100% of the CCS capacity is gas based
		I.a	**Biomass and gas plants**	Amount of biomass dedicated to power (both indigenous and imported) after exploiting all RES resources above, including biomass and electricity imports, any production still required is being covered with gas plants without CCS. Potential surplus is exported	30% of indigenous and imported biomass are being used for electricity production, this could lead to ~20 TWh of electricity, or ~20% of today's demand	40% of indigenous and imported biomass are being used for electricity production, this could lead to ~30 TWh of electricity, or ~30% of today's demand	50% of indigenous and imported biomass are being used for electricity production, this could lead to ~40 TWh of electricity, or ~40% of today's demand	60% of indigenous and imported biomass are being used for electricity production this could lead to ~50 TWh of electricity, or ~50% of today's demand

Table 7. Levers and ambition levels for energy supply (1/2).

Supply			Lever or trajectory	Description	1	2	3	4
Electricity	Imports	VII.a	Electricity imports					
			(i) Share of imports in total	Amount of electricity imported to Belgium	No net imports, Belgium is self-sufficient in its production of electricity over the year: imports and exports even out across the year	Belgium would go up to 5% imports if production is unsufficient (or ~4 TWh based on its 2010 production of 84 TWh)	Belgium would go up to 10% imports if production is unsufficient (or ~8 TWh based on its 2010 production of 84 TWh)	Belgium would go up to 20% imports if production is unsufficient (or ~17 TWh based on its 2010 production of 84 TWh)
			(ii) Share of RES in these imports	European electricity production mix imported by Belgium, and therefore cost of these imports and their impact on the transmission network. Imports are assumed to be based on a 100% low carbon mix	Average of the level 2 to 4	40% Renewable energy source, 30% CCS and 30% nuclear	60% Renewable energy source, 20% CCS and 20% nuclear	80% Renewable energy source, 10% CCS and 10% nuclear
Transmission		VII.c	Integration level of European transmission networks	Integration of the Belgian electricity transmission network with the rest of Europe compared to an optimal integration. The stronger the integration, the more Belgium plays an important role in European networks and the more it supports the optmized exploitation of intermittent RES at EU level. Stronger integration increases the investments requirements in transmission networks, and eases decarbonization for the rest of Europe. This could be attractive economically for Belgium with adequate transmission tariffs	Weak integration (25%) of the Belgian electricity transmission network with the rest of Europe compared to an optimal integration	Strong integration (50%) of the Belgian electricity transmission network with the rest of Europe compared to an optimal integration	Very strong integration (75%) of the Belgian electricity transmission network with the rest of Europe compared to an optimal integration	Complete integration (100%) of the Belgian electricity transmission network with the rest of Europe compared to an optimal integration

Table 8. Levers and ambition levels for energy supply (2/2).

D. SCENARIOS

D.1 Introduction

As mentioned earlier, the purpose of the study is to explore the different pathways that all lead to a reduction in GHG emissions of at least 80% in 2050 compared to 1990 in the current context of the nuclear phase out. As an almost infinite number of scenarios could be generated by playing with the levers, we have developed a coherent and consistent set of scenarios. These scenarios rely on commercially available technologies and solutions, with the important exceptions of CCS and to some extent geothermal electricity production which are still in the development phase.[46]

By taking into account realistic constraints and considering different plausible contributions from all the sectors, the scenarios illustrate some of the ways in which efforts and opportunities can be allocated across sectors to achieve the 80 to 95% reduction objectives.

It is impossible to predict the future and none of the scenarios in this analysis reflects a preferred pathway. Although this analysis takes a detailed look at what might be possible to achieve over the next 40 years, it does not set out what policy decisions would be required to deliver such a future.

The rest of this section “D. SCENARIOS” first describes these five low carbon scenarios and compares them, before detailing implications for the Reference and the Core scenarios. Section “E. SECTOR IMPLICATIONS” compares the modelled scenarios for each of the sectors and identifies key implications, also from a cost perspective while listing some of the barriers as well. Finally, section “F. OVERALL IMPLICATIONS” details some of the main implications that can be drawn when looking across scenarios.

Scenario description and comparison

Five decarbonisation scenarios have been developed (Figure 10), supplemented by some specific analyses or sensitivities. In each scenario, it has been assumed that industrial activity levels are similar to those under a ‘business-as-usual’ situation.[47] In other words, none of the five scenarios assumes that industrial production can be used as a lever for reducing emissions in the industry sector. On the contrary, the analysis implicitly suggests that the low carbon transition is compatible with a growing industry.

The following elements, amongst others, have been taken into account while making the choice of the scenarios:

- the choice of the scenarios should contrast complementary messages;
- the range of scenarios should reflect the various stakeholders' concerns and sensitivities;
- the scenarios should reflect the specificity of the approach used in this project (not based on optimization or simulation);
- the number of scenarios should not be too large for communication purposes (although the model can be used to develop an almost unlimited number of scenarios).

[46] Some of these applications are already commercially available – e.g. geothermal in Iceland, enhanced oil recovery with injected CO_2 in Norway, but need to be further developed, and their costs need to be reduced.
[47] This is not the case for the sectors where the low carbon transition impacts the activities, such as a stimulation of the glass and the bricks industries through the accelerated renovation of buildings or a reduction in the oil refineries activities due to a drop in the consumption of fossil fuels.

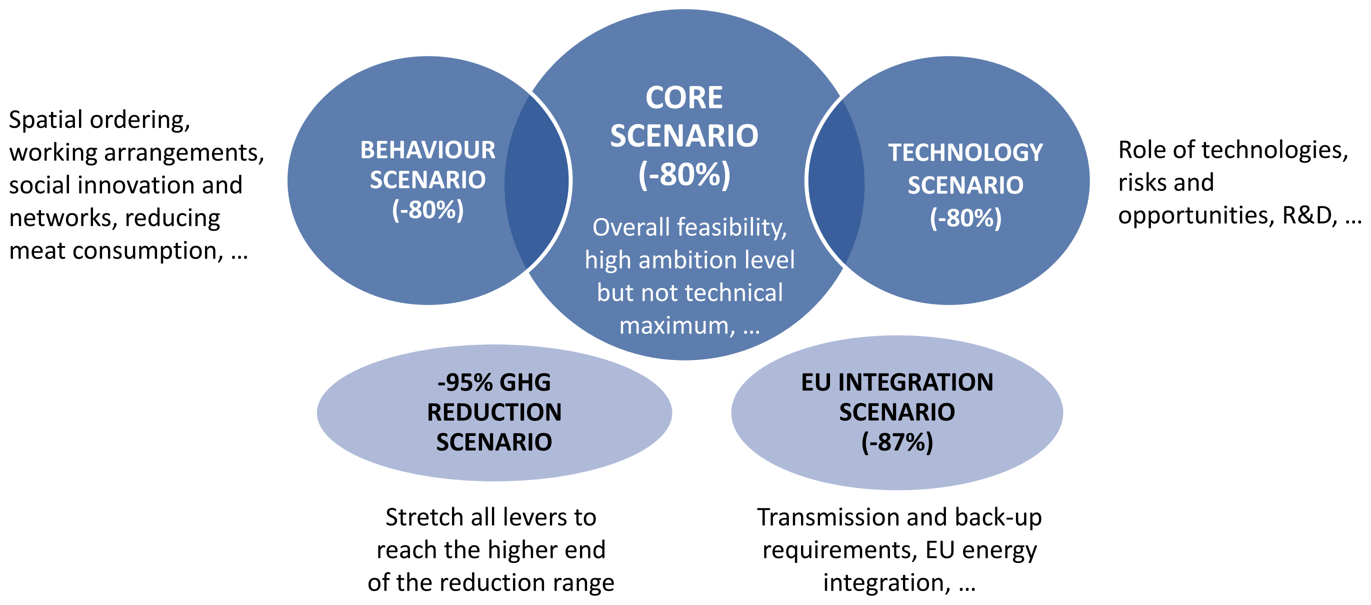

Figure 10. A set of 5 low carbon scenarios for Belgium reaching 80% to 95% GHG emissions reduction.

The "**REFERENCE**" scenario is built as a reference against which the five decarbonisation scenarios are evaluated. It is consistent with current legislation and achievement of the 2020 objectives of the European climate and energy package leading to a reduction of 15% GHG for non-ETS sectors for Belgium and to ~13% RES. However, no targets are specified after 2020: current trends in the various sectors are extended to 2050 and the levers are set at the first ambition level.

As far as possible, the reference scenario was matched with existing work from the Federal Plan Bureau and the recent 100% RES study based on the Times model (e.g., development of some of the key supply technologies).

Three decarbonisation scenarios that have been developed lead to 80% reduction in GHG emissions by 2050 with respect to emission levels in 1990: the CORE, BEHAVIOUR and TECHNOLOGY scenarios.

The "**CORE**" scenario strives to put to work all levers while not pushing them at their maximum. In practice, this scenario corresponds to the implementation of all levers around their 3rd level of ambition.

The other two scenarios leading to 80% reduction of GHG are developed around this "CORE" scenario. A "**BEHAVIOUR and SOCIETAL ORGANIZATION**" scenario (referred to as BEHAVIOUR scenario for simplicity) puts the emphasis on emission reduction possibilities through ambitious changes in behaviour, i.e. changes in lifestyles, such as a lower transport demand, less meat consumption, a lower level of heating and cooling in houses, etc. It implicitly assumes that all necessary cultural, structural, organisational and institutional changes needed to make possible this type of behavioural change are implemented (e.g., more investment in public transport, more working at home, climate change awareness raising, etc.). To keep it short, we refer to all these changes as 'behavioural', which does not imply an assumption that the changes in this scenario are the result of pure voluntarism. Levers related to such changes are set at their 4th level of ambition, which limits the reliance on technological levers with respect to the "CORE" scenario.

In contrast, a "**TECHNOLOGY**" scenario focuses on technological evolutions such as electrification levels in the transport and buildings sectors, process changes in industry, etc. Such levers are set at level 4. Behavioural changes are then less ambitious than in the "CORE" scenario. The purpose is to illustrate how far strong deployment of key technologies can lead us towards our decarbonisation goals. With fewer changes on the behaviour side, the use of technological abatement options must be stepped up to achieve the same reduction levels. Energy demand is higher and requires higher deployment of supply technologies, including CCS in the power sector.

A fourth scenario, called “**95% GHG REDUCTION**”, reflects the highest ambition in the GHG emission reduction target range. It is built to test the technical feasibility of a stronger GHG reduction by the year 2050. The technical boundaries of the various levers are set at level 4 to explore the maximum potential and resilience of all decarbonisation options. . It represents a major challenge for society, but not necessarily a complete paradigm shift (e.g. the industry production trajectories have been kept at the same level as in the REFERENCE scenario). It implies significant efforts from all actors in the society as lifestyles and societal changes need to be combined with large technical GHG reductions solutions including CCS. In this scenario all demand-side levers are set at their technical potential (level 4).

Finally, a fifth scenario called “**EU INTEGRATION**”, which reaches 87% GHG reduction, is described. It focuses on the supply side, namely by assuming high intermittency levels combined with higher European grid integration, heavier imports of electricity and larger amounts of back-up plants. This scenario is based on the assumption that European electricity grids are strongly developed and that European energy markets are highly integrated and share infrastructure. This scenario leads to an energy system largely based on renewable primary energy sources. Its purpose is to derive learnings on, amongst others, demand management, transmission and back-up requirements. Behavioural demand-side levers are set at similar levels as those selected in the REFERENCE scenario. On the supply-side, levers are set at a level that reflects the assumptions of the study ‘Towards 100% renewable energy in Belgium by 2050’ by VITO, the Federal Planning Bureau and ICEDD, which was published in December 2012.

As described in section “B.1. Methodology”, these scenarios are built by implementing each lever up to a certain ambition level. Table 9 and Table 10 below highlight how these ambition levels compare across the scenarios.

					Reference	Core	Behavior	Technology	-95% GHG	EU integration
Demand	Demographics			Demographic evolution	2	2	2	2	2	2
	Transport	Domestic	XII.a	**Domestic passenger transport**						
				(i) Overall travel demand per person	1	3	4	2	4	1
				(ii) Modal shift	1	3	4	2	4	1
				(iii) Energy efficiency	1	3	4	2	4	1
				(iv) Technology mix / electrification	1	3	4	3	4	4
			XII.b	**Domestic freight**						
				(i) Demand for freight transport	1	3	4	2	4	1
				(ii) Modal shift	1	3	4	2	4	1
				(iii) Energy efficiency	1	3	4	3	4	4
				(iv) Technology mix / electrification	1	3	3	4	4	4
	Buildings	Residential Heating	IX.a	**Domestic space heating and hot water**						
				(i) Compactness	1	3	4	2	4	1
				(ii) Heating / cooling comfort level	1	3	4	2	4	1
				(iii) Housing thermal efficiency	1	3	3	3	4	4
				(iv) Electrification level	1	3	2	4	4	4
				(v) Level of innovative heating technology	1	1	1	2	2	2
		Residential Lighting & Appliances	X.a	**Domestic lighting, appliances, and cooking**						
				(i) Demand / Efficiency	1	3	4	2	4	2
				(ii) Electrification	1	3	2	3	4	4
		Commercial Heating	IX.c	**Commercial heating and cooling**						
				(i) Heat / cooling demand	1	3	4	2	4	1
				(ii) Efficiency	1	3	4	3	4	4
				(iii) Electrification level	1	3	2	4	4	4
				(iv) Level of innovative heating technology	1	1	1	2	2	2
		Commercial Lighting & Appliances	X.b	**Commercial lighting, appliances, and catering**						
				(i) Demand / Efficiency	1	3	4	2	4	2
				(ii) Electrification	1	2	2	2	2	2
	Industry	Industry sectors	XI.a	**Steel Industry Production**	2	2	2	2	2	2
				Energy Intensity of Output	1	3	3	3	4	4
			XI.b	**Cement Industry Production**	2	1	1	1	1	1
				Energy Intensity of Output	1	3	3	3	4	4
			XI.c	**Lime Industry Production**	2	2	2	2	2	2
				Energy Intensity of Output	1	3	3	3	4	4
			XI.d	**Glass Industry Production**	2	1	1	1	1	1
				Energy Intensity of Output	1	3	3	3	4	4
			XI.e	**Chemicals Industry Production**	2	2	2	2	2	2
				Energy Intensity of Output	1	3	3	3	4	4
			XI.f	**Pulp & Paper Industry Production**	2	2	2	2	2	2
				Energy Intensity of Output	1	3	3	3	4	4
			XI.g	**Oil & Gas Industry Production**	4	4	4	4	4	4
				Energy Intensity of Output	1	3	3	3	4	4
			XI.h	**Food, drinks and tobacco Industry Production**	4	4	4	4	4	4
				Energy Intensity of Output	1	3	3	3	4	4
			XI.j	**Non-Ferrous metals Industry Production**	2	2	2	2	2	2
				Energy Intensity of Output	1	3	3	3	4	4
			XI.k	**Construction industry Production**	2	1	1	1	1	1
				Energy Intensity of Output	1	3	3	3	4	4
			XI	**Industry**						
				(iii) Carbon Capture & Storage	1	2	1	3	4	2

Table 9. Chosen ambition levels of the scenarios for demand side levers.

Sector	Category	Type	Code	Lever	Reference	Core	Behavior	Technology	-95% GHG	EU integration
Supply	**Energy prices**			Energy prices trajectories	3	1	1	1	1	1
	Electricity	Generation	III.a.1	**Onshore wind**	1	1.5	1.2	1.5	1.1	2.5
			III.a.2	**Offshore wind**	1	1.5	1.2	1.5	1.1	2.5
			IV.a	**Solar PV**	1	1.5	1.2	1.5	1.1	2.5
			III.b	**Hydroelectric power stations**	1	1.5	1.2	1.5	1.1	2.5
			III.d	**Geothermal electricity**	1	3	3	3	2.5	2.5
			IV.b	**Solar thermal**	1	3	2.5	3	2.5	2.5
			II.a	**Nuclear power**	1	1	1	1	1	1
			I.b	**Carbon Capture Storage (CCS)**						
				(i) Power Stations	1	1	1	2	1	1
				(ii) Power Station fuel mix	1	1	1	3	1	1
			I.a	**Biomass and gas power stations**	1	3	1.5	3	3	2.5
		Imported	VII.a	Imports of decarbonized electricity						
				(i) Share of imported electricity	1.5	1.5	1	1.5	1.5	3.5
				(ii) Share of RES in imported electricity	1	1	1	1	1	1
	Bioenergy	Generation	VI.a	**Agriculture and land use**						
				(i) Number of animals and meat consumption	1	3	4	2	4	4
				(ii) Emissions intensity per animal (enteric fermentation)	1	3	4	3	4	4
				(iii) Emissions intensity per animal (manure management)	1	3	4	3	4	4
				(iv) Evolution of soil emissions	1	3	4	3	4	4
				(v) Belgian indigenous biomass production	1	3	3	3	4	4
			VI.b	**Volume of Waste & Recycling**	1	3	4	2	4	4
		Imported	V.b	**Bioenergy imports**	1	3	4	3	3.5	4
	Electricity Balancing & Other									
	Balancing & Storage		VII.c	**EU transmission integration**	1	2	2	2	2	4

Table 10. Chosen ambition levels of the scenarios for supply side levers.

Summary Tables

Figure 11 illustrates the level of GHG emissions in each scenario. It is worth noting that agriculture constitutes a significant block of emissions in all scenarios in 2050. As for industry, it requires the use of CCS in four scenarios ('CORE', 'TECHNOLOGY', 'EU INTEGRATION' and '-95% GHG') and even CCS with biomass in one of them ('-95% GHG').

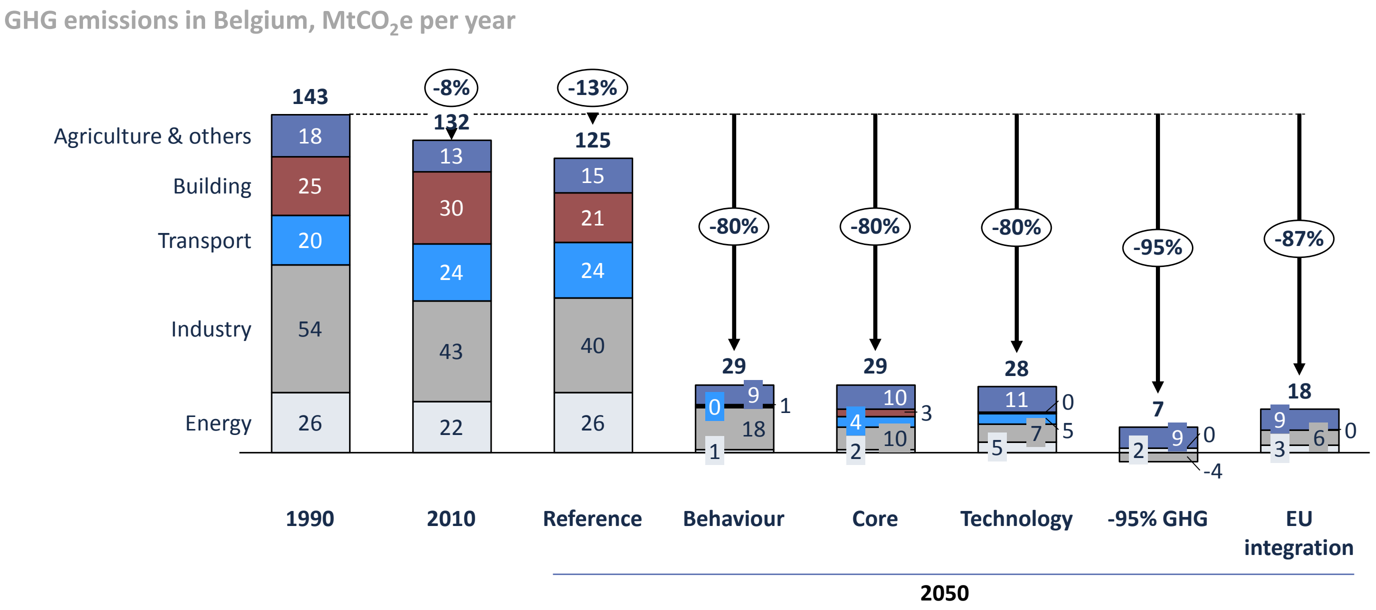

Figure 11. Comparison of the GHG emission reductions in all scenarios.

Figure 12 just below gives a view on the main indicators characterizing the scenarios in 2050. Implications of these scenarios at the sector level and overall messages on the low carbon transition in Belgium are presented in the following sections.

	Units	REFERENCE	CORE	BEHAVIOUR	TECHNOLOGY	-95% GHG	EU INTEGRATION
GHG emissions wrt 2010 (1990)	%	**-6% (-13%)**	**-78% (-80%)**	**-78% (-80%)**	**-79% (-80%)**	**-95% (-95%)**	**-86% (-87%)**
Buildings[1]	%	-32% (-17%)	-89% (-87%)	-98% (-98%)	-99% (-99%)	-100% (-100%)	-100% (-100%)
Transport	%	-1% (+18%)	-82% (-79%)	-98% (-98%)	-81% (-77%)	-99% (-99%)	-98% (-98%)
Industry	%	-7% (-27%)	-76% (-82%)	-58% (-67%)	-83% (-86%)	-109%[2] (-107%)[2]	-86% (-89%)
Power	%	+12% (-6%)	-98% (-98%)	-98% (-98%)	-86% (-88%)	-96% (-97%)	-96% (-96%)
Agriculture & waste	%	+9% (-19%)	-27% (-46%)	-36% (-52%)	-17% (-38%)	-36% (-52%)	-36% (-52%)
Energy demand wrt 2010 (1990)	%	+17% (+55%)	-35% (-14%)	-45% (-27%)	-29% (-6%)	-53% (-38%)	-39% (-19%)
Biomass use	(TWh)	69	98	107	99	110	119
CCS	(MtCO2e)	0.0	-9.4	0.0	-17.7	-14.3	-4.4
Electricity							
Consumption in 2050	(TWh)	135	104	88	126	89	140
Consumption wrt 2010 (1990)	%	+56% (+128%)	+20% (+76%)	+2% (+48%)	+46% (+114%)	+3% (+51%)	+62% (+137%)

1 Emissions are compared to actual 2010 figures which were particularly high due to a very cold year. The model uses an average number of degree-days leading to lower emissions in 2010.

2 Industry emissions reductions in the -95% GHG scenario (-109% GHG (-107%)) are the result of a combination of CCS and biomass allowing industry to achieve negative GHG emissions while keeping the same industry trajectories as in the other scenarios. Alternatively, the -95% GHG scenario could be built with lower industry trajectories that would result in other GHG profiles.

Figure 12. Main indicators of the 5 scenarios in 2050.

In the rest of this section D, the REFERENCE and the CORE scenarios are described in detail while the other scenarios are described in “Appendix 2 – Description of the alternative scenarios”. Overall results in terms of GHG emission reductions as well as on key characteristics of the energy system are presented. We refer to the following sections for cost implications: “E. SECTOR IMPLICATIONS” and “F. OVERALL IMPLICATIONS”.

D.2 Reference scenario (REF)

The REF scenario includes existing policies and assumes that beyond existing targets or incentives the parameters continue to develop at the same pace. It does not include additional policies to reduce GHG emissions and serves as a baseline scenario for comparison with the other modelled scenarios. The scenario takes into account the objectives of the 2020 EU Climate-Energy package and the federal and regional agreed climate-energy policies.

The assumptions in this scenario are for the most part in line with those used in the reference scenario of the study ‘Towards 100% renewable energy in Belgium by 2050’.

Context and demography

The REF scenario implies no additional decarbonisation efforts in Belgium or abroad. As described in the methodology section, Energy prices[48] reflect the prices of the 6°C scenario of the latest Energy Technology Perspectives (ETP) 2012 report by the IEA.[49i]

Demographic assumptions are based on the latest study of the Federal Plan Bureau,[50] with a population growth of 16% between 2010 and 2050. With a combined drop in the number of people per household from 2.28 to 1.97 (0.4% p.a.), the number of households in Belgium increases by 39% by 2050.

Transport

In the REF scenario, the transport demand per person across all transport modes increases by ~20% (passengers-km/person). The car occupation level drops while the occupation levels of buses and trains rise by 10%. This evolution is in line with the Federal Planning Bureau’s long-term projections for an unchanged policy.

The share of the various individual transport modes does not evolve compared to 2010, with cars representing 77% of all the kms travelled (in line with Federal Planning Bureau’s expectations for 2030). Internal combustion engines still dominate the market: 20% of the fleet is based on plug-in hybrid technology and 5% is electric (10% for buses).

Energy efficiency of the various technologies keeps improving: individual internal combustion engines, plug-in hybrids and electric cars become ~30% more efficient than today’s fleet while the efficiency gains in public and freight transport vary between 5% (ICE lorries) and 15% (hybrid and electric buses).

Freight transport continues to grow and remains coupled with the expected annual economic growth:[51] annual growth of transported volumes is 1.6% until 2030 and ~0.8% per year from 2030 resulting in an overall growth of 60% of the tons transported in 2050 vs. 2010. The share of lorries (of which the vast majority is diesel) increases to 75% of the tons-km transported, the share of rail stabilizes at ~12% and the inland waterways decreases to ~13%.

[48] In the model, energy prices have an impact only on costs (the energy bill) that do not play any explicit role in the development of the scenarios since OPEERA does not optimize based on costs.
[49] IEA ETP 2010 and 2012, WWF "The energy report", ECF 2050 Roadmap.
[50] Based on the Federal Plan Bureau (“Perspectives on population 2012-2060” of May 2013) and own projections.
[51] GDP growth still induces an increase in transport but the link becomes weaker.

Buildings

With increased wealth, the average internal temperature is assumed to rise to 20°C by 2050, representing a significant increase of 2°C vs. 2010; hot water demand per household in 2050 increase with 20%. There is no change in the compactness of dwellings.

The final energy consumption of new dwellings reaches 'very low energy house' standard (30kWh/m²) by 2020 according to requirements at the European level. Minor improvements take place in existing dwellings and result in a decrease in average heat demand to 111 kWh/m² in 2050, compared to ~140 kWh/m² in 2010.

The renovation rate of existing dwellings per year is maintained at the same level as today (1%) which means that ~40% of all dwellings are renovated in 2050.

By 2050, 20% of the installed heating installations in the residential stock are heat pumps (air & ground source). Innovative technologies such as district heating with cogeneration and micro-CHP represent 10% of the all installed non-electric heating technologies.

The energy demand for lighting, appliances and cooking increases by 25% due to a significant increase mainly in black appliances and to some extent in domestic appliances, together with a stabilization in demand for lighting.

The energy demand for cooling increases significantly, in the services sector as 90% of the offices will be actively cooled in 2050 vs. 66% in 2010 and in the residential sector where the cooling demand reaches 60% of the households in 2050 vs. 4% today.[52]

Industry

The analysis considers various trajectories of the future production by industrial sector and describes the possible pathways in the various sectors and subsectors.[53] These trajectories were defined on the basis of stakeholder consultations with each of these sectors. As a result, the 'middle' trajectory (which is used for most of the sectors with the exception of glass, cement and ceramic industry) sometimes differs from the production trajectories used in the "Towards 100% RES in Belgium by 2050" study (which were based purely on the results for Belgium of macro-economic modelling on the European level).[54]

For example, for the Steel sector, 3 trajectories are modelled: (1) a growth of 0.46%/year until 2050 (2) the stabilization of the production at the level of 2010 and (3) a reduction of 1.7% per year leading to a production of steel halved in 2050.

The REF scenario considers energy efficiency gains realized through commercially available technologies, except for CCS. This current technology approach assesses the decarbonisation by applying a broad mix of technologies that have been thoroughly discussed with key industry experts.

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[52] Including reversed heat pump.

[53] For instance, there is no one 'chemical' sector but instead sub-chemical industries, as organic and non-organic chemistry, fertilizers, industrials gazes and Para-chemicals.

[54] The differences in the production trajectories of the two models arise from their respective methodologies: in OPEERA energy efficiency measures have a much stronger impact on the result than in the TIMES model. Whereas in TIMES electricity consumption drops only 4 % between the base-year and 2050 in OPEERA this amounts to 35%. For fuels we observe a drop of 21% in TIMES and 52% in OPEERA in the same time span.

Almost a hundred of GHG reduction levers have been identified and sequentially applied. They refer to the evolution of the product mix, potential energy efficiency gains, potential process improvements and the use of alternative fuels. The application of these levers results in the description of an energy and carbon intensity per unit of output.

Sector	**Production (2050 vs. 2010)**	**Energy and Carbon intensity per output (2050 vs. 2010)**
Steel	Stabilized production	• Increase of electro-steel by 17%
Cement	Stabilized production	• Clinker substitution by steel slag reduces energy & process emissions by 15%, • Energy efficiency increases by +13%
Lime	Stabilized production	• Energy efficiency increases by +13%
Glass	Stabilized production	• Energy efficiency increases by +8%
Chemicals	Stabilization of the ETS sectors; increase of 20% of the non-ETS	• Status quo
Pulp & paper	Stabilized production	• Energy efficiency increases by +10%
Oil & gas refineries	Correlated to fuel demand in the transport and buildings sector	• Energy efficiency increases by +10%
Food & Drinks	Correlated to agriculture production	• Energy efficiency increases by +10%
Non-ferrous metals	Stabilized production	• Energy efficiency increases by +5%
Ceramic	Growth of +2.5% between 2015-2025; stable after 2025 (+44% by 2050)	• Energy efficiency increases by +10%

Agriculture (non-CO_2) and waste

The REF scenario assumes that emissions stay relatively constant as the volume of the underlying activity grows lightly. With an increasing population and similar diets, the meat consumption results in a net increase in the number of animals; this leads to ~43 million animals in Belgium in 2050.[55] There are no specific changes in the European common agricultural policy.

In terms of soil emissions, there is an overall stabilization of direct N_2O emissions as the impact of an increase of nitrogen input to agricultural soils is offset by a decrease in agricultural land. The emissions from grazing increase as

[55] These trends are based on the extensive work done for the reference scenario of the “Toekomstverkenning 2030” work by the Vlaamse Milieumaatschappij.

nitrogen excretions per animal increase due to improved nutrition in support of productivity growth. This all leads to an increase in overall agricultural emissions of 0.11% per year up to 2030, and stabilization after that up to 2050.

In the waste sector, GHG emissions are stabilized at the current level.

Energy supply

The REF scenario assumptions lead to an increase in final energy demand from ~435 TWh to ~505 TWh (Figure 13).

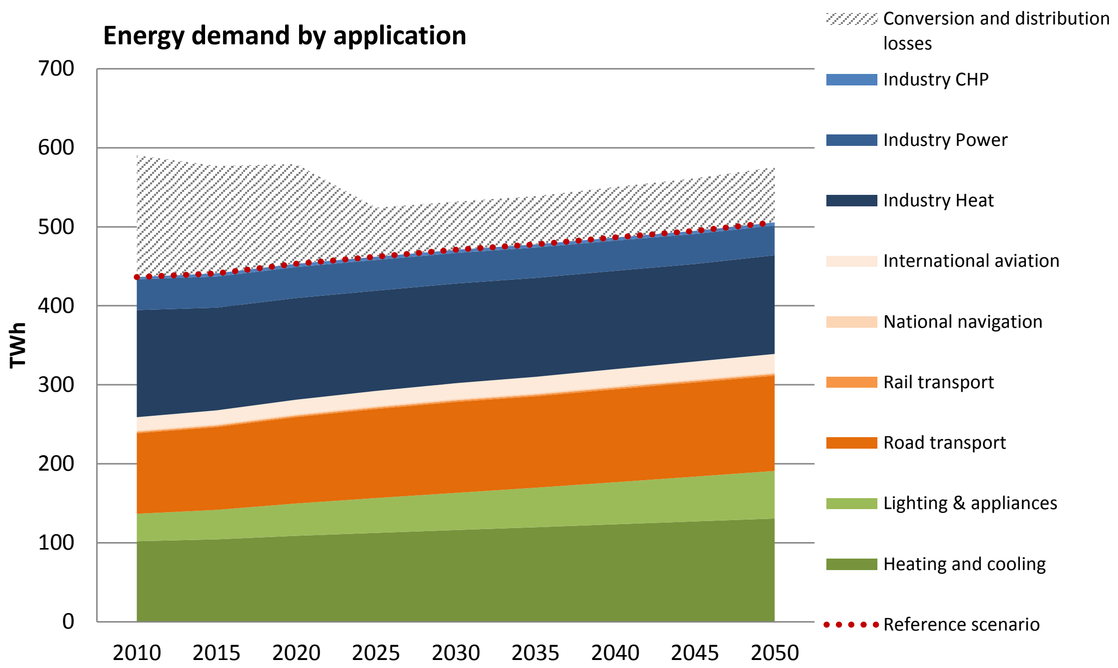


Figure 13. Energy demand in the REF scenario.

Heat supply[56] today is heavily based on fossil fuels sources (coal, gas and petroleum), and the REF scenario assumes that this continues up to 2050. Energy from sustainable biomass, both indigenous and imported, roughly stabilizes in the REF scenario. Heat pumps only take a small share of the market with a small increase in the contribution of heat based on electricity and environmental heat over time. The overall amount of energy required increases slightly over time as the population and the number of households increases, which is only lightly balanced by limited efforts to significantly curb energy consumption.

Electricity production follows current policies to 2020 and extends them to 2050, leading to the following evolutions: nuclear electricity production disappears completely by 2025, leaving room for a significant amount of gas production, as well as RES production from wind, solar and biomass with intermittent RES representing ~30% of the mix. Neither geothermal energy nor CCS is used in electricity production (Figure 14).

[56] Heat is meant here as all forms of energy supply other than electricity and includes fuel for transport.

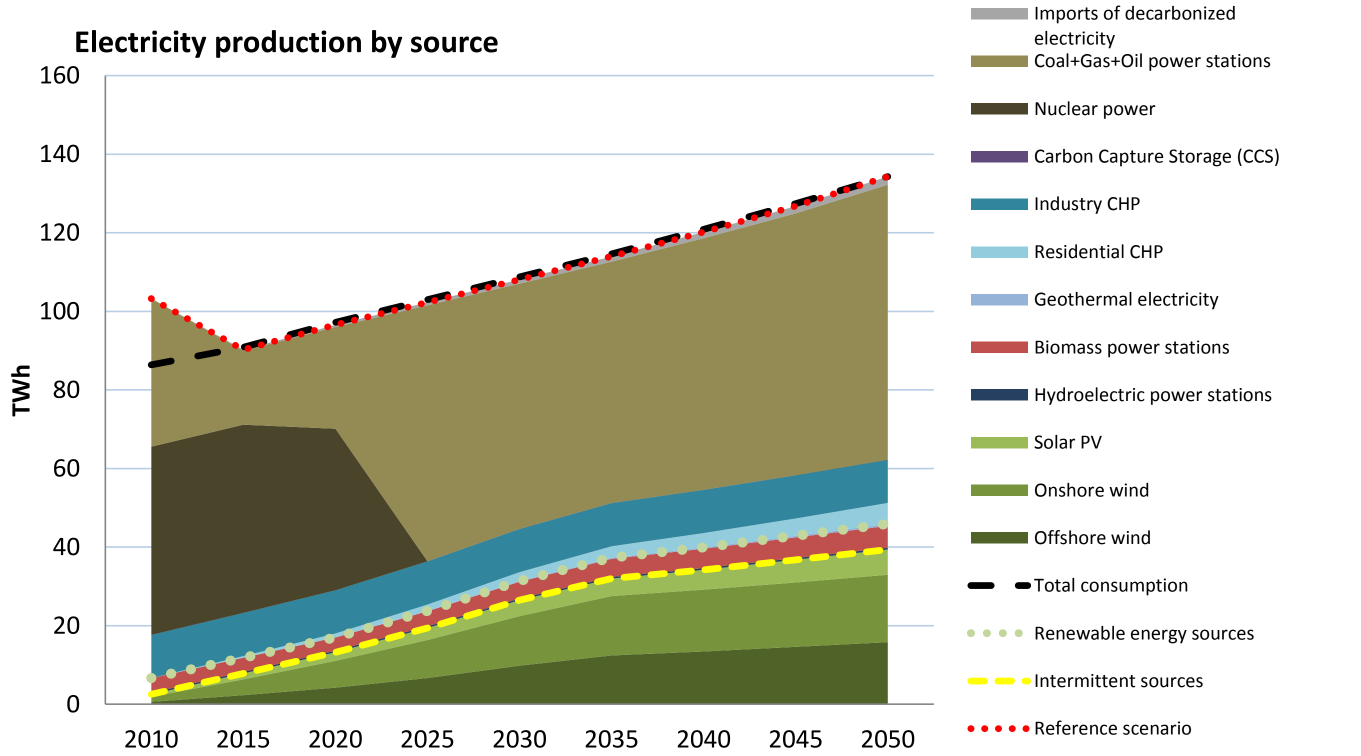


Figure 14. REF, Electricity production by source.

Onshore wind capacity increases up to ~7 GW in 2050, roughly doubling the 3 GW capacities planned in 2020 in the Belgian NREAP. This requires installing 260 MW per year, or approximately 100 new turbines per year (including replacements).[57]

In line with the 100% RES project reference scenario, offshore wind capacity increases up to 2 GW in 2020 (the NREAP goes to 1,3 GW) and ~4 GW in 2050. This requires installing 120 MW per year, or approximately 20 new turbines per year[57].

In line with the 100% RES project reference scenario, solar PV capacity reaches 2,5 GW in 2020 (higher than the 1,3 GW of the NREAP which has already been surpassed in 2012) and ~7 GW in 2050, or ~9% of 2010 Belgian electricity production. This requires annual growth to decrease to ~150 MW/year up to 2020, and then slowly increase back to ~400 MW/year in 2050 (average of 250 MW/year over the 40 years).

Installed hydroelectric capacity reaches 110 MW (no new installations by 2050) and developments in conventional geothermal production are limited (no enhanced production). No significant development is assumed in solar thermal power and CCS is not used in electricity production.

Nuclear exit is assumed as per the latest federal legislation.[58]

Imports of electricity are set are their historic level in the past few years, imports and exports netting out to ~5% of its production of electricity over the year.

[57] The maximum capacity of 6.4 GW (onshore) and ~3 GW (offshore) is reached by 2035, and from then on turbines are simply replaced at the end of their 25 years lifetime.

[58] Shut down Doel 1 & 2 (0,4 GW each) in the spring of 2016, shut down of Doel 3 (1 GW) in 2022, closing of Tihange 2 (1 GW) in 2023, closing of Tihange 1 &3 and Doel 4 (1 GW each) in 2025.

The indigenous biomass potential is exploited to reach Belgian objectives of 13% RES in final energy demand by 2020. Exploitation then increases progressively to reach 100% of the potential identified by Valbiom in Wallonia, and Ovam in Flanders in 2050 (altogether ~24 TWh of biomass and biogas).

Biomass imports increase gradually to 10 TWh/year in 2020 and then stay constant to 2050.

Resulting GHG emissions

The REF scenario results in a decrease of 14% in the GHG emissions in 2050, from 143 MtCO2e in 1990 to 132 MtCO2e in 2010 and 124 MtCO2e in 2050. This result is very distant from the low carbon objectives.

The REF scenario reflects a 9% increase in Agriculture, a stabilization of Transport emissions, a decrease of 7% of the GHG emissions in Industry and 35% of Building emissions while the energy production sectors increase GHG emissions by ~11%, between 2010 and 2050.

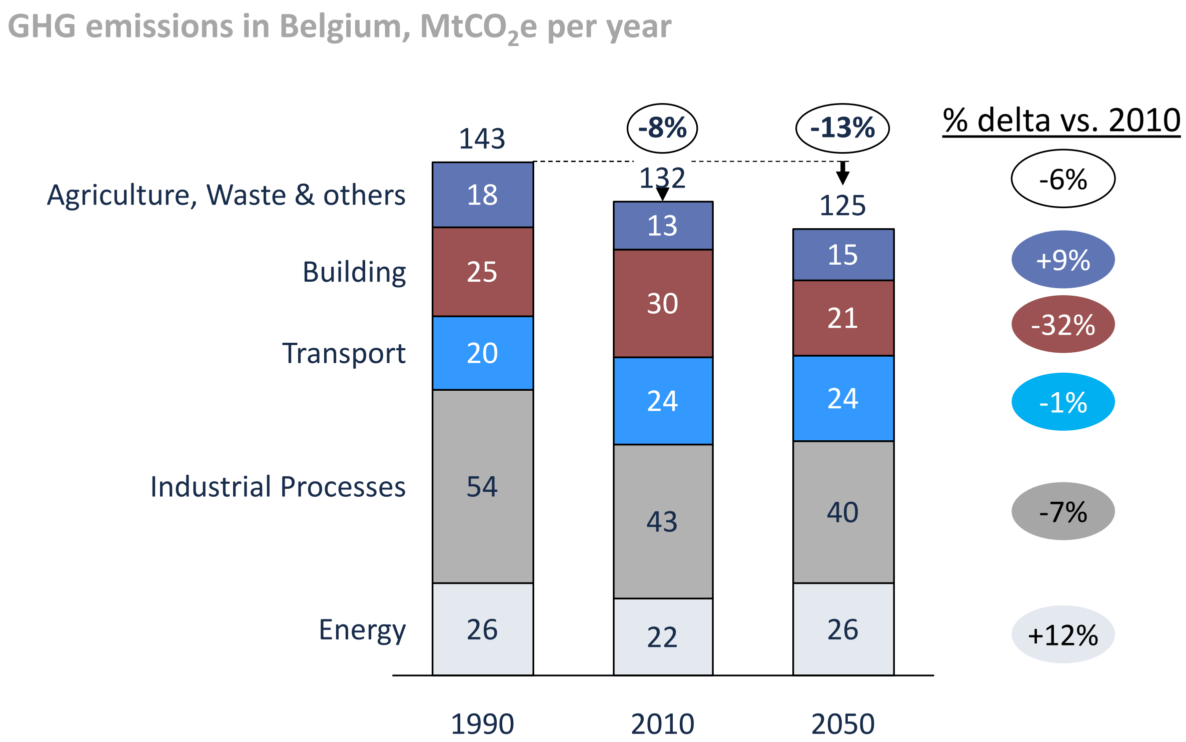


Figure 15. REF scenario, GHG emissions, sectoral view.

D.3 « CORE » low carbon scenario

The "CORE" scenario achieves 80% GHG emission reduction through mobilising all levers while not pushing them to their maximum: this scenario corresponds to the implementation of the levers at their 3rd level of ambition. It is clear, however, that this level 3 ambition implies significant efforts, requiring non trivial cultural changes, large financial investments and significant technology developments.

Context and demography

Like in the REF scenario, population growth follows the FPB projections with an expected growth of 16% between 2010 and 2050 and an increase in the number of households by 39% by 2050. Demography plays a significant role in GHG emissions. Section "F.3. Sensitivities" discusses the impact of demography on GHG emission.

As described in the "Methodology" section above, the low carbon scenarios are built on the assumption that Belgium is not isolated in its decarbonisation efforts. Hence, energy prices reflect the levels of the 2°C scenario of the latest Energy Technology Perspectives (ETP) 2012 report by the IEA.

Transport

The transport demand per person (passengers-km) decreases by ~10%. The occupation level of cars increases by 10% while the occupation levels of buses and trains rise 33% and 25% respectively.

The share of the various individual transport modes evolves, with the car representing 65% of all the distance travelled (from 77% in the REF scenario), the share of walking and cycling grows from 3% to 4%, the share of rail increases from 7% to 10% and the share of bus transport from 13% to 20%.

80% of the car fleet is plug-in hybrid, battery electric or fuel cell while internal combustion engines only represent the remaining 20%; buses follow a similar evolution. This evolution and the lowering of the ICE share will continue even after 2050.

Energy efficiency (km driven by unit of energy) of the various technologies keeps improving: individual internal combustion engines are ~45% more efficient than the current fleet, plug-in hybrids and electric cars become ~50% more efficient than today's fleet while the efficiency gains in public and freight transport vary between 25% and 30%.

The freight grows with ~20% between 2010 and 2050. The share of lorries (of which 60% are diesel and ~40% hybrid) drops to 65% of the tons-km transported, the share of rail grows to ~ 15% and inland waterways represent ~20%.

Buildings

Average internal temperature in households is kept at the current level, namely 18°C, hot water demand per household drops by 20% in 2050 and 20% of Belgian households effectively use air conditioning by 2050.

The final energy consumption of new dwellings reaches 'very low energy house' standard (30 kWh/m²) by 2020 and the level of a passive house (15 kWh/m²) in 2030.

Renovation speed and/or post-renovation performance of the buildings are doubled. The renovation speed reaches 2% per year as from 2020, twice as high as the current renovation speed. Adapted technologies ensure a high level of wellbeing while using very low levels of energy.

The proportion of multi-family buildings in the new dwellings increases up to the level of 60% by 2030 and remains constant after 2030.

By 2050, 60% of the installed heating installations in the residential stock are heat pumps (air & ground source). Innovative technologies such as district heating with cogeneration and micro-CHP represent ~10% of the rest of the heating installations.

The energy demand for lighting, appliances and cooking increases: the stabilization of the demand for lighting is combined with a significant increase mainly in small appliances and to some extent in domestic appliances.

Industry

Within industry, GHG emissions are abated through a broad mix of technologies, the evolution of the product mix, potential energy efficiency gains, potential process improvements and the use of alternative fuels. It is worth mentioning that this scenario considers that significant portions of the GHG emission are reduced through new technologies, one of which could be CCS.

Even though activity in the refinery sector slackens in the low-carbon scenarios, we consider it possible that investments in low-carbon technologies may still made in this sector. This could reflect the reality of a shrinking global refinery capacity in a carbon-constrained world, where only the most efficient plants stand a chance a survival in a testing business environment.

Significant improvements in existing technologies and coordination of support development for large scale deployment of existing and new technologies could enable even deeper emission cuts in the long term.

Sector	**Production (2050 vs. 2010)**	**Energy and Carbon intensity per output (2050 vs. 2010)**
Steel	Stabilized production	• Increase of electro-steel by 17%, • +25% shift to high processability steel, • 5% improvement of overall energy efficiency in integrated steel production, • Introduction of Hisarna technology (closing of coke and sinter plants) enabling +35% efficiency, • Coal substitution at 3% by gas injection, • Coal PCI substitution at 15% by biomass
Cement	Growth of +0.23% per year (+10% by 2050), supported by the building sector	• Clinker substitution by steel slag reduces energy and process emissions by -53%, • Energy efficiency increases by +34%, • Fuels substituted at 66% by solid biomass
Lime	Stabilized production	• Energy efficiency increases by +30%, • Lignite is substituted at 66% by gas, • Fuels are substituted at 20% by solid biomass
Glass	Growth of +1.7% per year (doubling by 2050), with hollow glass remaining stable	• Energy efficiency increases by +30%, • Cullet use increases by +10%, • Oxyfuel use increases efficiency by +24%, • Liquid fuel is substituted at 100% by gas in 2030, • Solid fuels are substituted at 6% by solid biomass
Chemicals	Stabilization of the ETS sectors;	• Penetration of 20% green chemistry, replacing traditional plastics, • 20 to 30% energy efficiency gains,

	increase of 20% of the non-ETS	• 90% reduction of N2O emissions
Pulp & paper	Stabilized production	• Energy efficiency increases by +20%, • Liquid fuel is substituted at 100% by gas in 2030, • Solid fuels substituted at 85% by biomass in Kraft pulp mill
Oil & gas refineries	Reduction of ~1%/year, correlated to the evolution of fuel demand in the transport and buildings sector.	• Energy efficiency increases by +30%, • 15% extra implementation of CHP, • Liquid fuel substituted at 50% by natural gas, • Process improvement starting from 2030 resulting in 15% reduction energy use
Food & Drinks	Correlated to agriculture production	• Energy efficiency increased by +30%; all solid and liquid fuels switched to gas; gas substituted at 50% by biogas
Non-ferrous metals	Stabilized production	• Energy efficiency increases by +20%; all liquid fuels substituted by gas; gas substituted at 50% by biogas
Ceramic	Growth of +3.5% per year between 2015-2025; stable after 2025 (+68% by 2050). Production driven by demand for bricks for new buildings	• Energy efficiency increases by +30%; all solid & liquid fuels substituted by gas; gas substituted at 50% by biogas
New technologies to abate GHG emissions, e. g. CCS		• All installations producing above 1 $MtCO_2e$ /year are equipped with CCS and their residual emissions are reduced by 85%

Agriculture (non- CO_2) and waste

The CORE scenario assumes that emissions related to Agriculture and waste decrease with 29% over 2010 and 46% over 1990, through a combination of measures, of which reduced meat consumption, some improvements in the use and the efficiency of nitrogen, reduced emissions from grazing. There are no specific changes in the European common agricultural policy.

The waste sector has not been analysed in detail in this study, but its GHG emissions are assumed to decrease linearly by 75% to reach 0.3 $MtCO_2e$ in 2050.

Energy supply

The CORE scenario assumptions lead to a decrease in final energy demand from ~435 TWh to ~270 TWh (Figure 16).

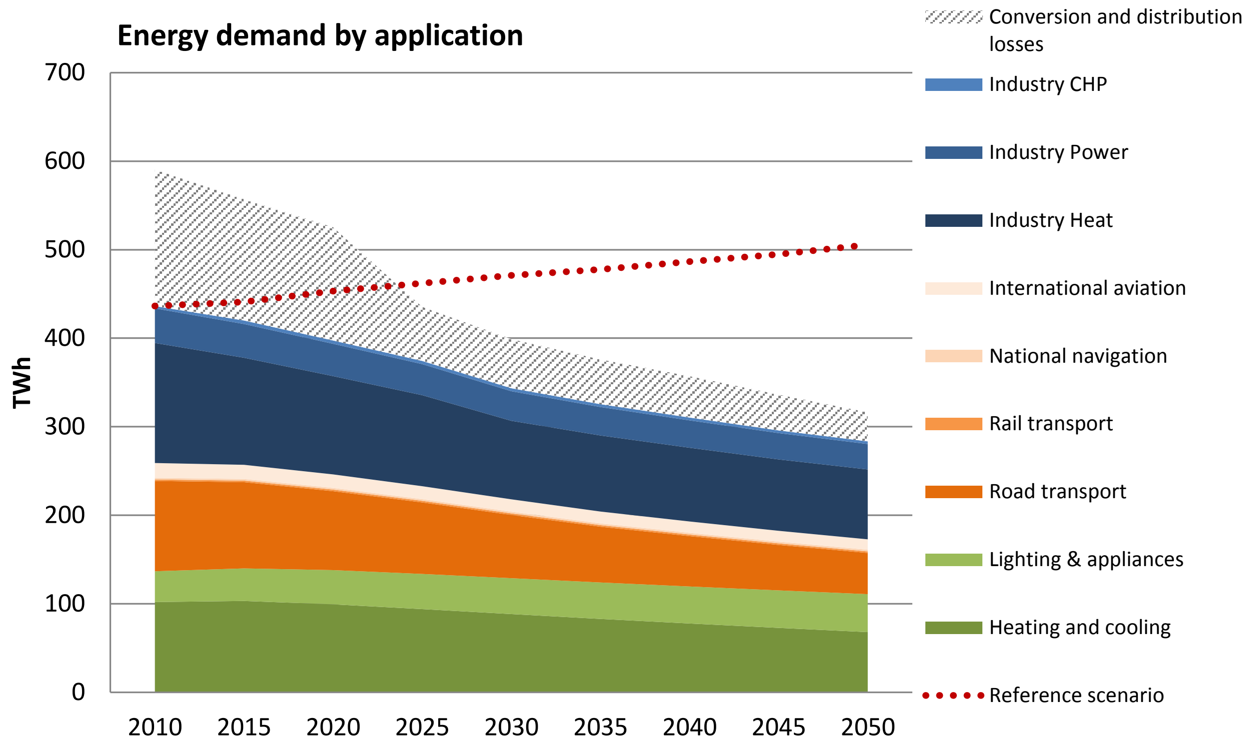


Figure 16. CORE, Energy demand.

Electricity production (Figure 17): nuclear electricity production disappears completely by 2025 and is replaced by more gas production (although to a lesser extent than in the REF) and RES production. As from 2025, the share of gas decreases as RES production from wind, solar, biomass, geothermal and CHP see their role increasing. Intermittent RES represents ~50% of the mix in 2050. Imports of carbon-free electricity represent ~5% of the total supply.

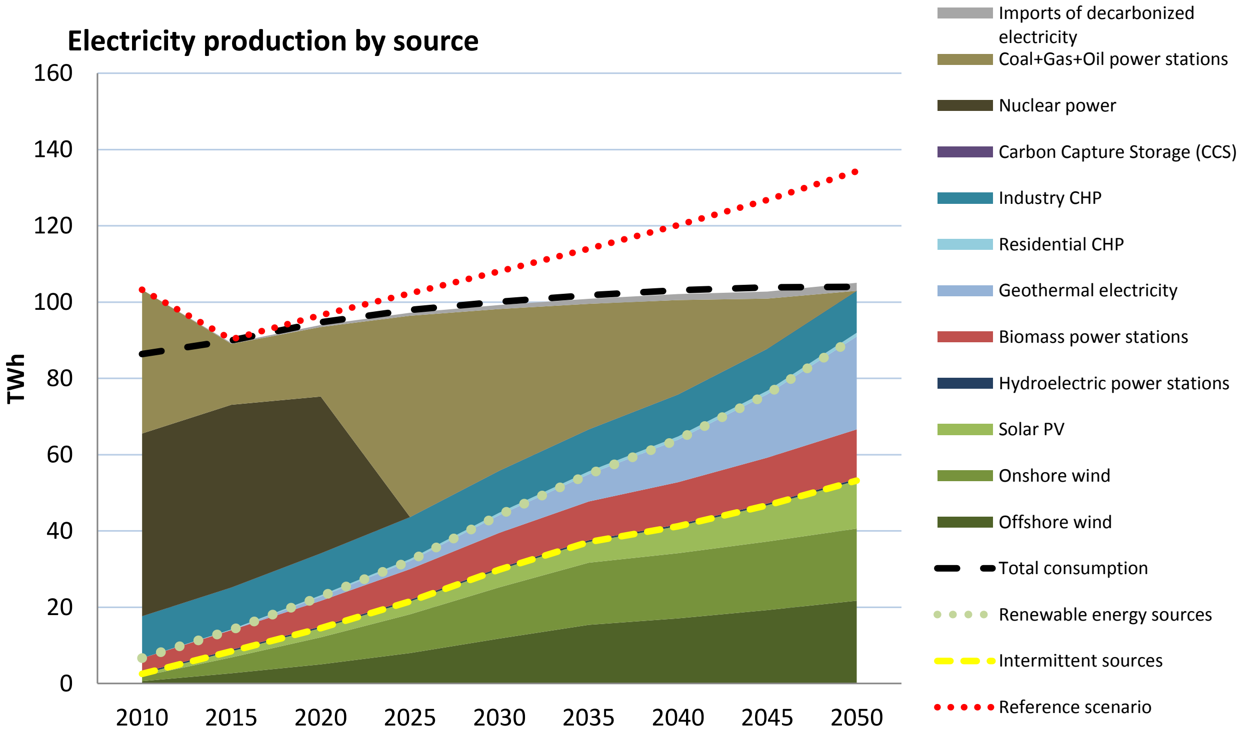


Figure 17. CORE scenario, Electricity production by source.

Onshore wind capacity increases up to ~8 GW in 2050 (vs. 7 GW in the REF scenario). This requires installing on average 300 MW, or ~120 new turbines per year. Offshore wind capacity increases up to ~5.5 GW in 2050 which requires installing on average 200 MW, or ~40 new turbines per year. Replacement rates of 25 years are assumed for both types of wind electricity generation.[59]

Regarding solar PV, annual growth is ~200 MW/year up to 2025 and then slowly increases to ~1100 MW/year in 2050 (average of 500 MW/year over the 40 years). Solar PV capacity reaches ~14 GW in 2050.

Developments in conventional geothermal production are limited due to limited potential. However, there is a gradual implementation of enhanced geothermal, with 200 MW in 2025, rapidly ramping up to reach 3 GW of installed capacity in 2050. Hydroelectric capacity increases by 20 MW in 2050, reaching 130 MW.

There is no CCS in electricity production.

100% of the biomass potential identified by Valbiom in Wallonia, and Ovam in Flanders is exploited in 2020 (altogether ~27 TWh of biomass and biogas). The biomass potential remains stable after that, and biogas production increases progressively to reach the full potential identified by Edora in Wallonia en 2050 (~3 to ~9 TWh, bringing total potential to 36 TWh).

The level of bioenergy imports is consistent with the estimated maximum sustainable amount of biomass production worldwide when this potential is distributed equally per person at the world level leading to ~80 TWh of potential for Belgium (including ~34 TWh of indigenous production).

Resulting GHG emissions

Figure 18 illustrates the GHG emissions in the CORE scenario, reaching an **80% reduction** in 2050 over 1990. Industry and Agriculture represent the highest GHG emitting sectors with each 10 $MtCO_2e$ of the 28 $MtCO_2e$ remaining in 2050 while Transport and Buildings decrease significantly. Energy production is almost zero carbon.

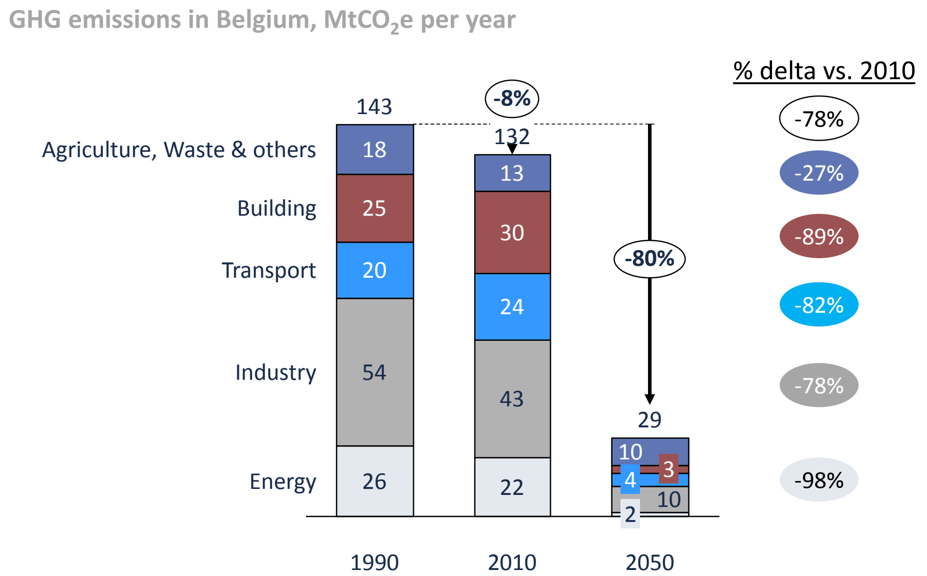


Figure 18. CORE scenario, GHG emissions, sectoral view.

[59] The onshore wind capacity reaches 7 GW and then plateaus. From then on turbines are mainly replaced at the end of their 25-year lifetime. Offshore wind grows more continuously, but the amount of refurbishments increases significantly as of 2035.

E. SECTOR IMPLICATIONS

E.1 Transport sector

Scenario implications

Transport is a sector with a large GHG reduction potential through combined efforts to both reduce transport demand and apply appropriate technologies. Various trajectories lead to drastic reductions in GHG emissions in the transport sector by 2050, from 77% below the 1990 level (in the TECHNOLOGY scenario) to 99% (in the -95 GHG scenarios).

Direct GHG[60] reduction in transport compared to 2010 (1990) including biomass impact	REF	CORE	BEH	TECH	-95%	EU Integration
Total	-1% (+18%)	-82% (-79%)	-98% (-98%)	-81% (-77%)	-99% (-99%)	-98% (-98%)

Figure 19 illustrates how energy demand for domestic transport is impacted by the reduction levers. Applying behavioural and societal levers (this applies mainly passenger to transport demand) first makes it possible to use technical levers to a lesser extent to achieve similar GHG reduction. In the BEH scenario, compared to the REF 2050 figures, energy demand is reduced by 57% through reduced transport demand and increased modal shift while these levers only reduce the demand by 21% in the TECHNOLOGY scenario. Consequently, energy efficiency and electrification have to reduce the energy demand by only ~20 TWh in the BEHAVIOUR scenario to reach 90% energy demand reductions, while they need to reach ~27 TWh in the TECHNOLOGY scenario to reach only 82% reductions.

[60] Direct GHG emission only represents a share of the total GHG emission. For Transport, the carbon content of imported goods could be significant.

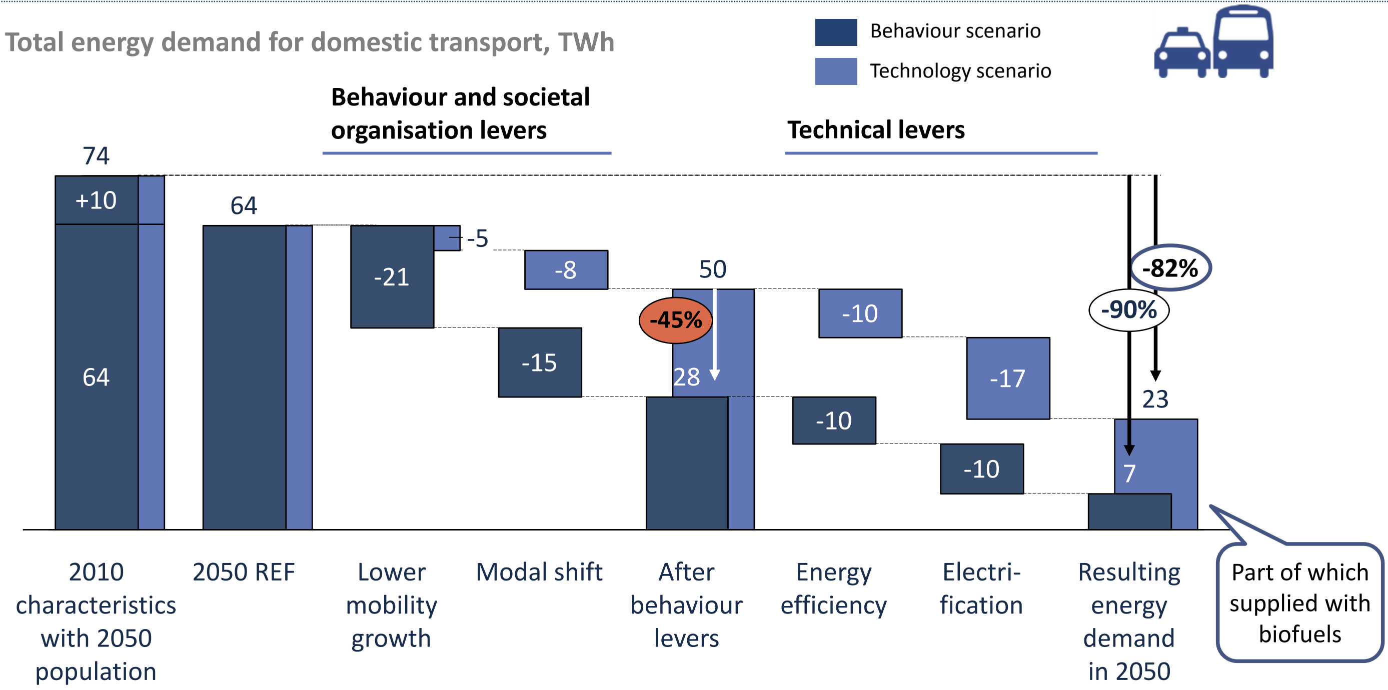


Figure 19. Impact of various levers on Transport energy demand in the BEH and the TECH scenarios.

Figure 20 compares the total passengers transport demand and its distribution per mode in the REFERENCE and CORE scenarios. The significant increase in the REFERENCE scenario is due to the combination of a larger population with a higher travel demand per person. In the CORE scenario, the volume of total transport demand increases by only 4% compared to 2010 due to a lower travel demand per person. The shift towards alternative modes is such that in the CORE scenario car travel amounts to only 65% of total transport, in comparison with 77% in the REFERENCE.

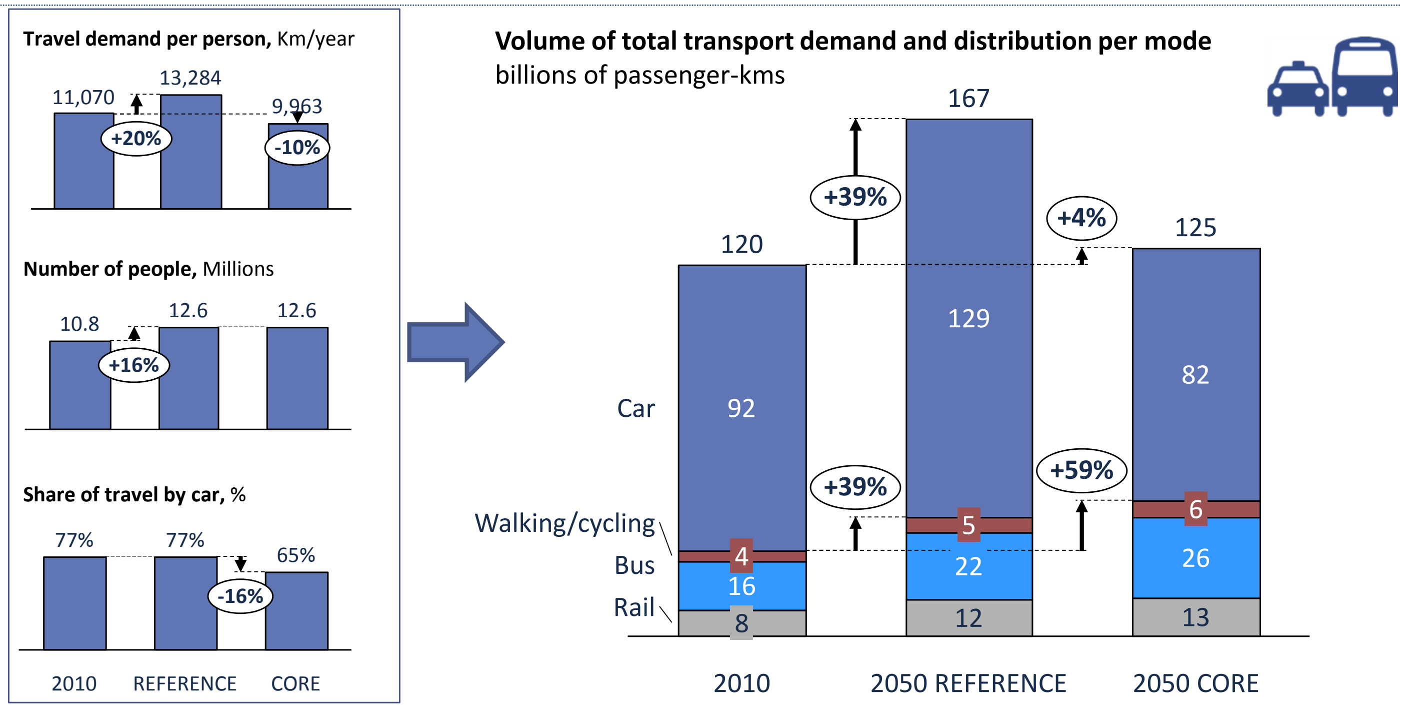


Figure 20. Impact of key drivers on total transport demand, and distribution of that demand across modes.

As shown in Figure 21, the low carbon transition implies an almost complete shift to electric transport by 2050: in the CORE scenario, 80% of the car fleet in 2050 is composed of plug-in hybrid, battery electric or fuel cell cars. This electrification of the sector makes it possible to improve the energy efficiency of transport as electric vehicles are more efficient than internal combustion engines. It is also coherent with an energy supply system that reduces GHG emissions through the introduction of renewable energy sources in electricity production. The figure also shows that the REF scenario with more people and an increase in travel demand (in line with what has been observed recently) presents significant challenges: more than 8.4 million cars or an increase of 60% over today that would affect health and congestion issues.

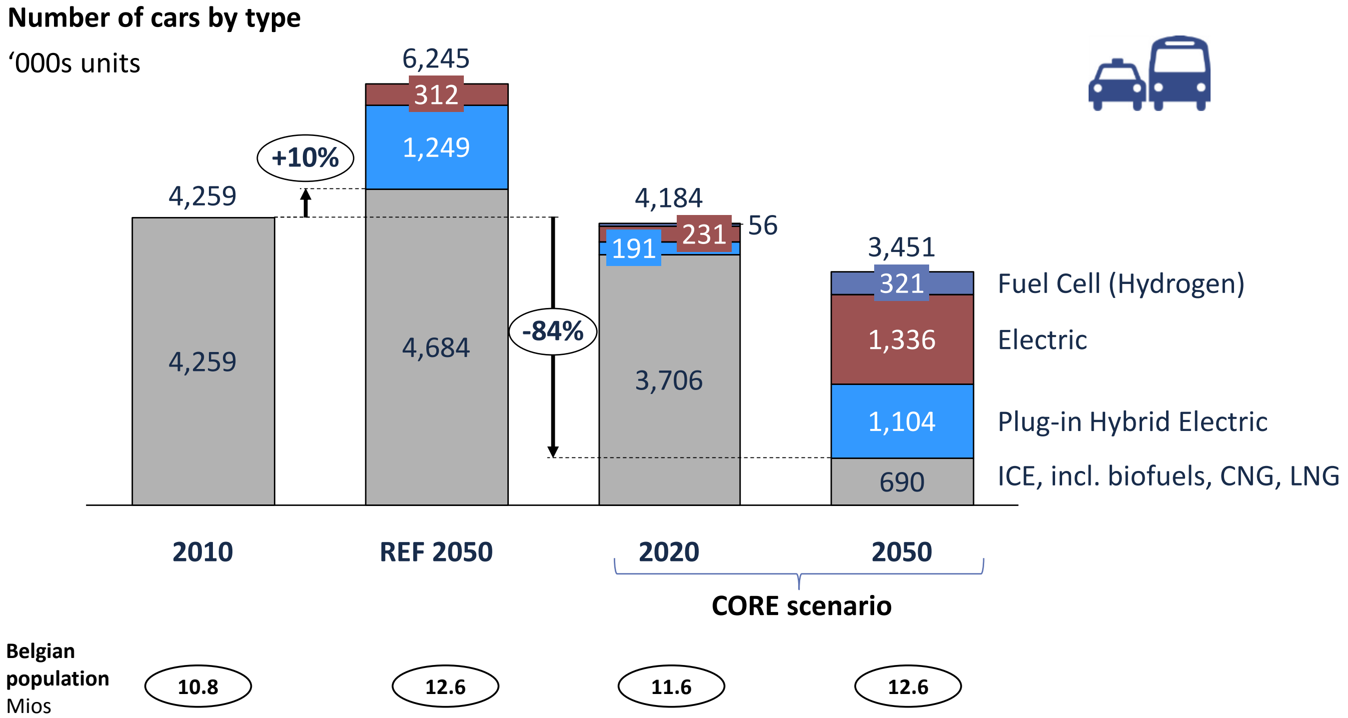


Figure 21. Details of the car fleet in various scenarios.

Costs

The main investment costs taken into account for Transport refer to investment in vehicles and infrastructure (including replacement of the fleet over time, replacement of electric vehicles, and cost of the electric charging infrastructure). O&M costs of the various vehicles are taken into account, as well as fuel costs based on their usage.

Figure 22 below shows the cost implications for domestic transport of the car fleet, the bus/rail/bike fleet, and the total transport system costs in the REF and the CORE scenario. As expected, the lower travelled distances by car lead to much lower costs. In the meantime, public transport costs increase, but to a lesser extent since the CORE scenario assumes overall lower travelled distances than in the REF scenario, longer lifetimes of public transport vehicles and higher vehicle occupation rates. Altogether, domestic transport could be ~20% cheaper in a low carbon scenario. This of course has very different implications for private and public stakeholders, but the lower budgets required for cars would likely shift to public transport with higher uses.

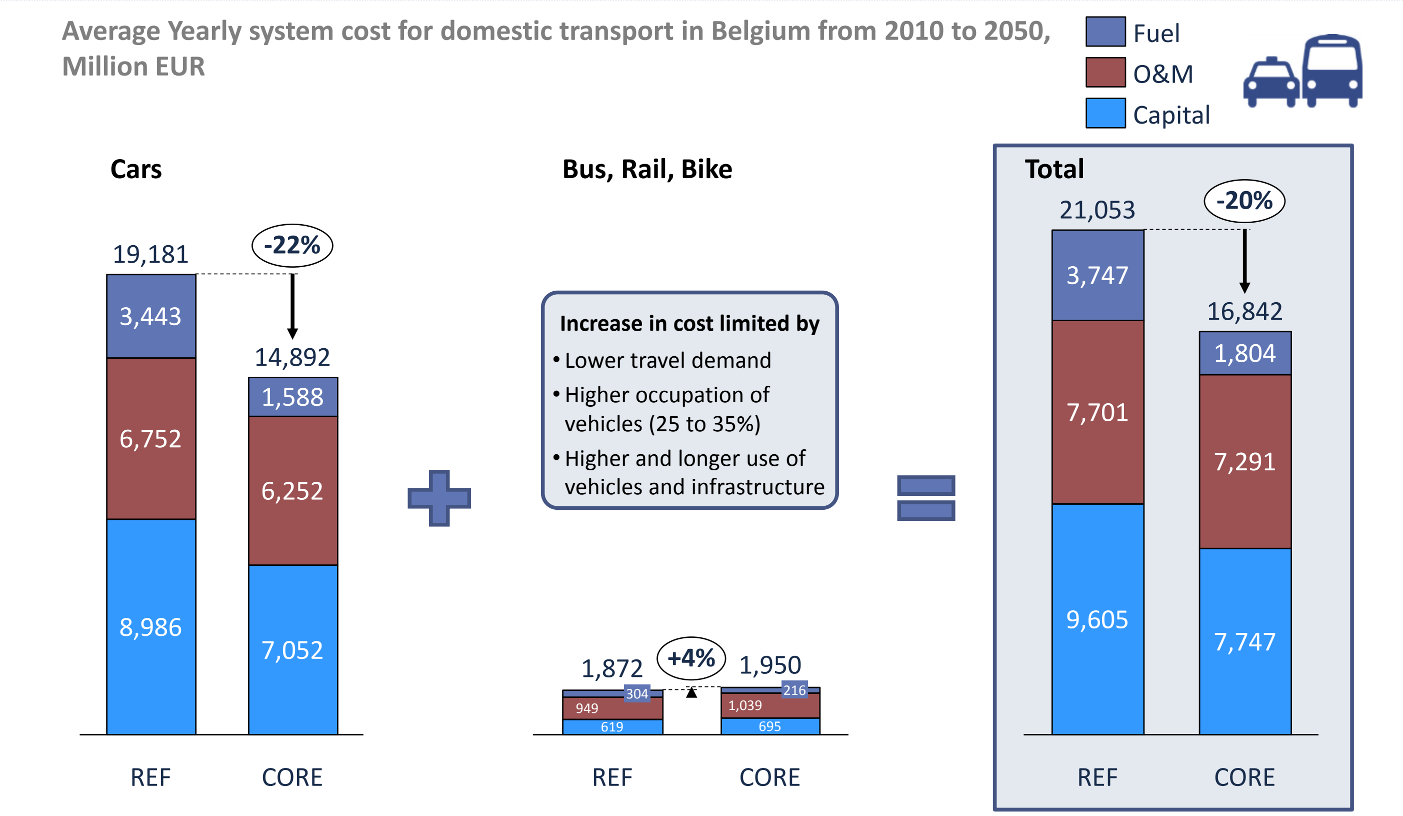


Figure 22. Cost implications in the Reference and Core scenarios for domestic transport.

Barriers[61]

The transport sector, including vehicle manufacturing, the availability and use of sustainable bioenergy and the development of intelligent transport systems, is driven at global level. However, a range of coordination measures, interventions, investments, supporting schemes and behavioural changes at the Belgian level could be required to enable changes in transport activity.

Impact on spatial planning, e.g. densifying around large economic and living centres and land use changes, will need to be integrated in more coherent and coordinated transport policies at the various decision levels, in close collaboration with the neighbouring regions.

To enable significant growth in soft transport modes such as cycling, lifestyle change would be required, accompanied by additional infrastructure and complementary measures, for example a re-allocation of road space. The higher levels of demand on public transport illustrated in the more ambitious levels below would likely require more dense networks as well as complementary infrastructure such as interchanges, multi-modal platforms and waiting facilities.

Changes to driving behaviour and occupation rates (driving fewer kilometres with more people per vehicle) could also result in emission reductions but variations in travel patterns could make this hard to achieve. Further work on understanding how to remove organizational and psychological barriers as well as the training of professionals and the development of competences should, like in neighbouring regions, be encouraged.

[61] Not exhaustive.

E.2 Buildings

Scenario implications

In the same way as transport, the buildings sector has a large GHG reduction potential, through combined efforts to reduce energy demand and apply appropriate technologies. The low carbon trajectories serve to abate GHG emissions in buildings by 84%-96% by 2050 with respect to 1990. The table below shows the percentage reductions reached in each of the scenarios.

Direct GHG reduction in buildings compared to 2010 (1990) including biomass impact	REF	CORE	BEH	TECH	-95%	EU Integration
Total	-32% (-17%)	-89% (-87%)	-98% (-98%)	-99% (-99%)	-100% (-100%)	-100% (-100%)

Given the strong correlation of building energy consumption to seasonal and annual variations in weather conditions, in all scenarios we assume a constant number of degree days of 1799 (15/15 in Uccle)[62] from 2010 until 2050. This allows us to compare the impact of the various reduction measures between scenarios because the concept of constant degree-days neutralizes the weather impact. In the above table, 1799 degree days are also assumed for 2010 instead of the real degree days (2010 was an extremely cold year: 2308 degree days), in order to increase the comparability between projection years and the base year 2010.

Increasing the performance of the building envelopes is crucial for reducing the overall energy consumption of the sector. One of the essential measures to reach a more energy efficient building park is through ambitious standards for new buildings. Considering the long lifetime of buildings, relying on the high energy performance of new buildings alone will not be sufficient to reach emission reductions on the order of 80-95%.Consequently, attention should be paid to improving the current building park as well. Renovation speed and/or post-renovation performance of the buildings should be amplified. Improving the performance of the building park might induce additional emissions in other sectors (industry, transport,…) due to increased activity in the short term. But these should be largely compensated over time. Inversely, intelligent urban planning (densification) can potentially reduce emissions in other sectors as well. Several technologies are at hand to provide the heating and cooling inside homes and tertiary buildings. These technologies present different energy efficiencies, carbon intensities and decarbonisation potentials. Behavioural changes (lower average temperatures of heating and sanitary hot water) can reduce the need for technical interventions and thus aid in reaching ambitious GHG targets.

The next figure shows the impact of behavioural and organisational levers versus the impact of technical levers. A highly efficient building stock and a large deployment of heat pumps have a strong impact on emissions by 2050. Decreasing or limiting the increase of average temperature in buildings can also contribute significantly to the total emission reductions.

[62] 1799 degree days corresponds to the average temperature conditions in the period 2000-2009 (Uccle).

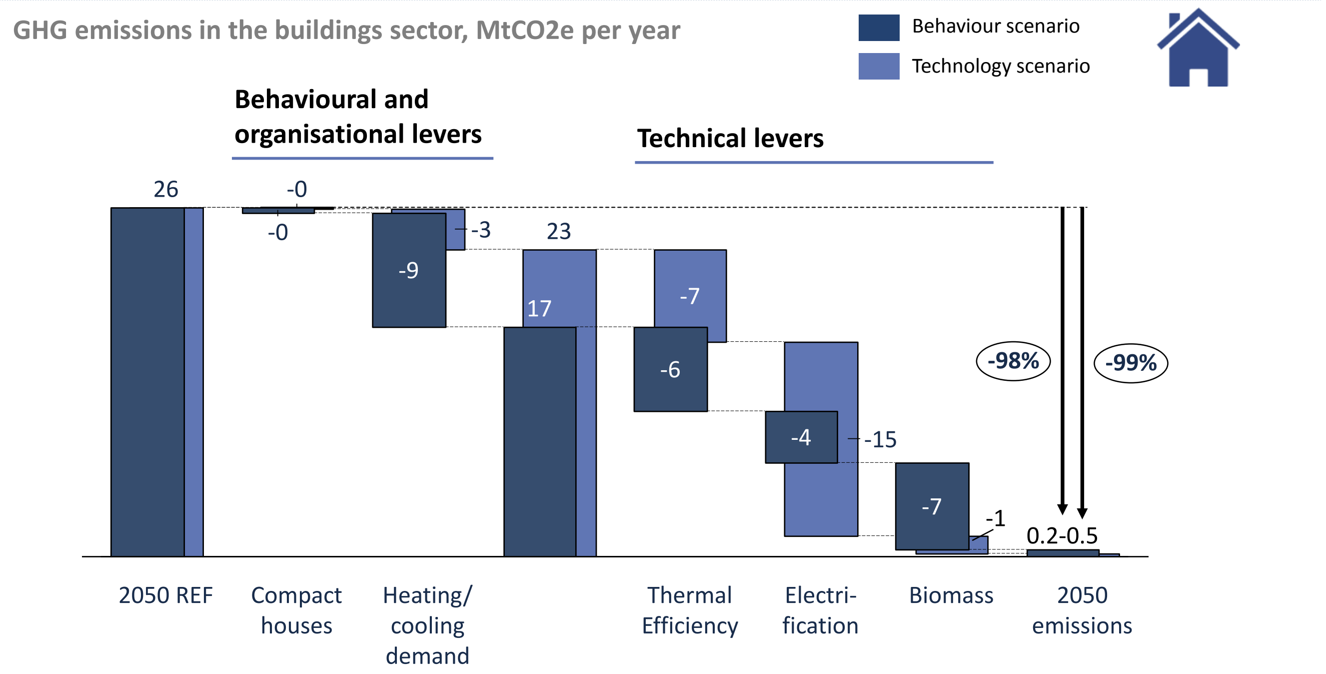
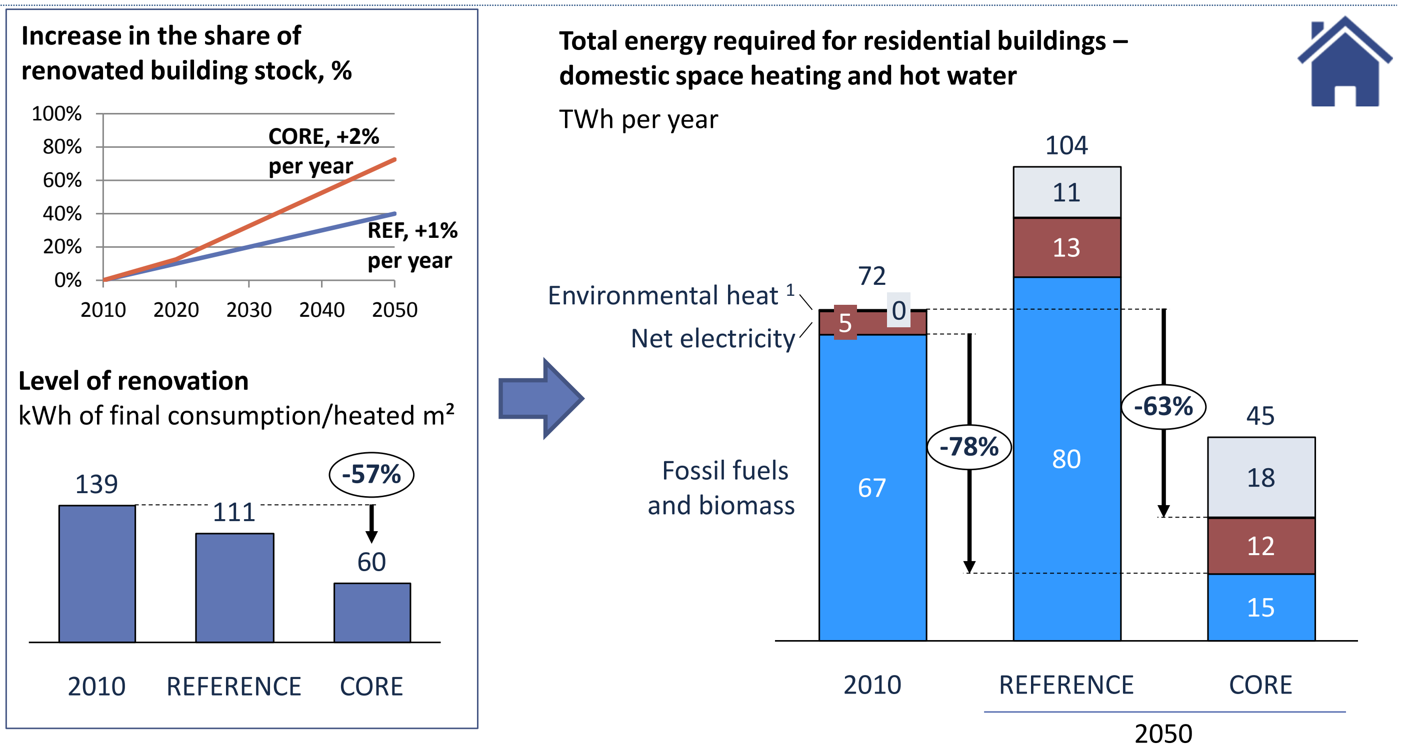


Figure 23. Impact of various levers on Buildings energy demand in the BEH and the TECH scenarios.

Given the large share of old buildings in the Belgian stock, the rate and level of renovation will strongly impact the total GHG emissions by 2050. The rate and level of renovation doubles in the CORE scenario compared to the REFERENCE scenario. Besides the renovation rate and level, the type of heating installations has a strong impact on final energy demand, as shown in Figure 24. Replacement of fossil fuel heating systems by environmental heating systems (mainly heat pumps) significantly lowers final energy demand of buildings.



1 Energy extracted from the atmosphere by heat pumps (ground and air) and from sun rays by solar thermal systems

Figure 24. Impact of key drivers on total buildings energy demand, and distribution of that demand across supply type.

Concretely, Figure 25 shows how the amount of heating systems increases with the amount of households up to 2050, but most importantly how the mix is drastically different between the reference and the CORE scenario, with heat pumps increasing their share.

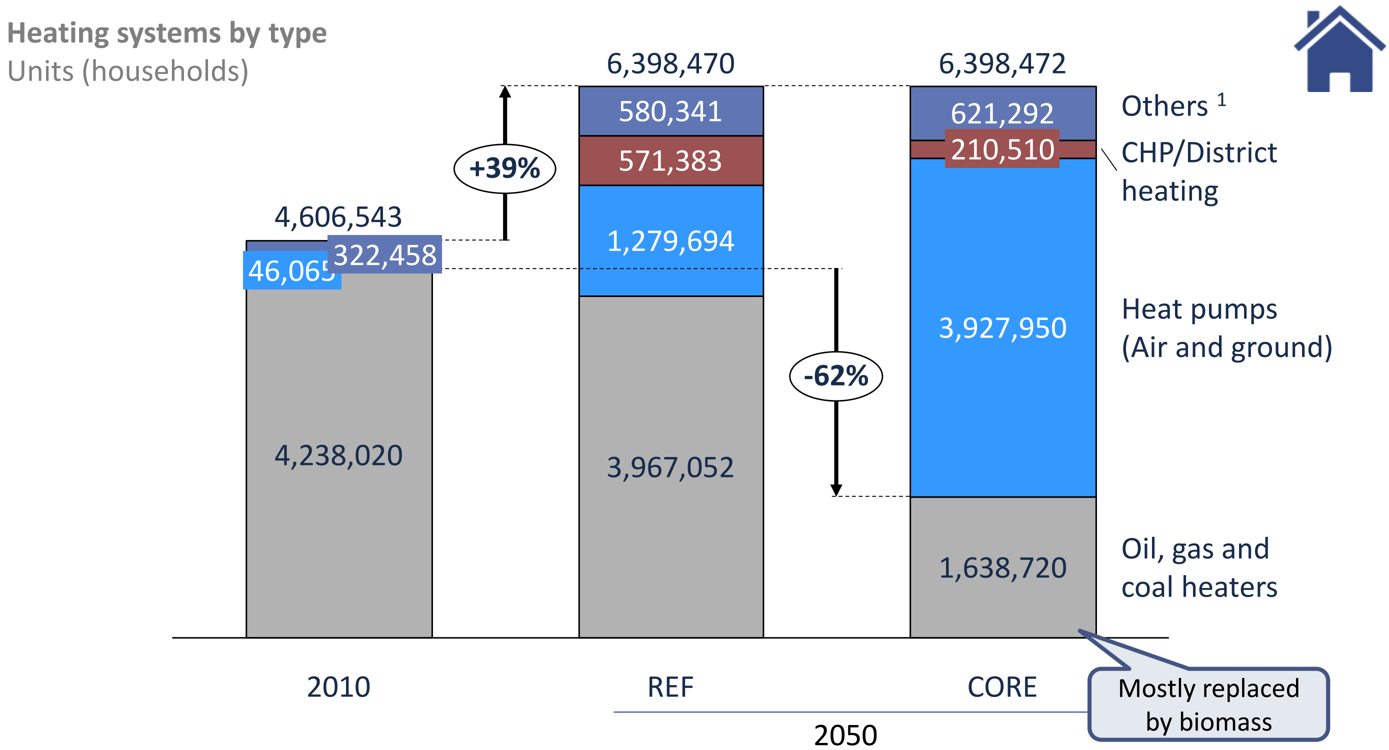


Figure 25. Impact of key drivers on total buildings demand, and distribution of that demand across supply type.

Costs

The figures below show in greater detail the costs involved in the low-carbon transition for the buildings sector. Overall, the total undiscounted system costs for the low-carbon scenarios are higher than for the reference scenario. The 'core' scenario is 4% more expensive; the 'behaviour' and 'technical' scenario have similar cost levels as they are both at 3 in terms of efficiency with some variations in terms of the level of electrification. The other 2 scenarios have much higher costs as they both require level 4 efficiency levels for houses, which means refurbishing levels end up being very extensive (see Figure 26). Investment costs (in new buildings, renovations and new heating & cooling installations) are by far the most dominant cost factor in the buildings sector. Indeed, the total cost of the reference scenario includes the total cost of new buildings, of the heating systems and the total cost of renovation. Therefore it is not limited to the additional capital or operational costs related to the emission reduction measures or to the additional costs compared to autonomous replacements of e.g., heating systems. The fuel costs in the low-carbon scenarios are lower than in the reference scenario, but they do not compensate for the higher investment costs in the time frame under consideration.

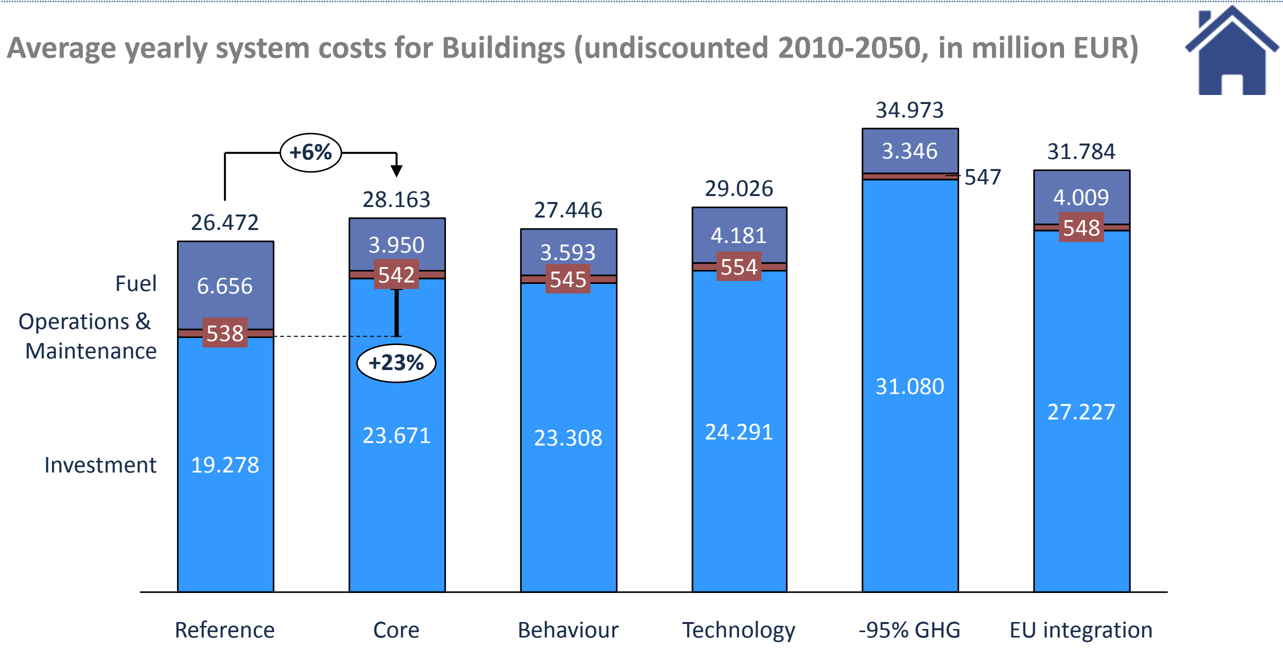


Figure 26. Total system costs in Buildings in the various scenarios.

Figure 27 shows in more detail the investment costs in the CORE scenario. New buildings account for the largest share of the average yearly investment costs in the buildings sector in the CORE scenario (~50%). The sharp increase of these costs compared to the REF scenario (+ 17%) is due to higher investment costs in houses requiring lower fuel costs, and these higher costs are indeed partly compensated over time as shown above. The installation of more expensive heating technologies also leads to higher investment costs (61% of demand for heat is provided by heat pumps). The limited lifetime of heating installations (15 -20 years) results in high investments in all the scenarios due to replacement of old installations. Finally, investment costs for renovations to improve insulation are about 3 times higher in the CORE scenario (compared to the REF scenario) since about twice as many houses are renovated to a 'low energy house' post-renovation standard (with an average heat demand of 60 kWh/m²).

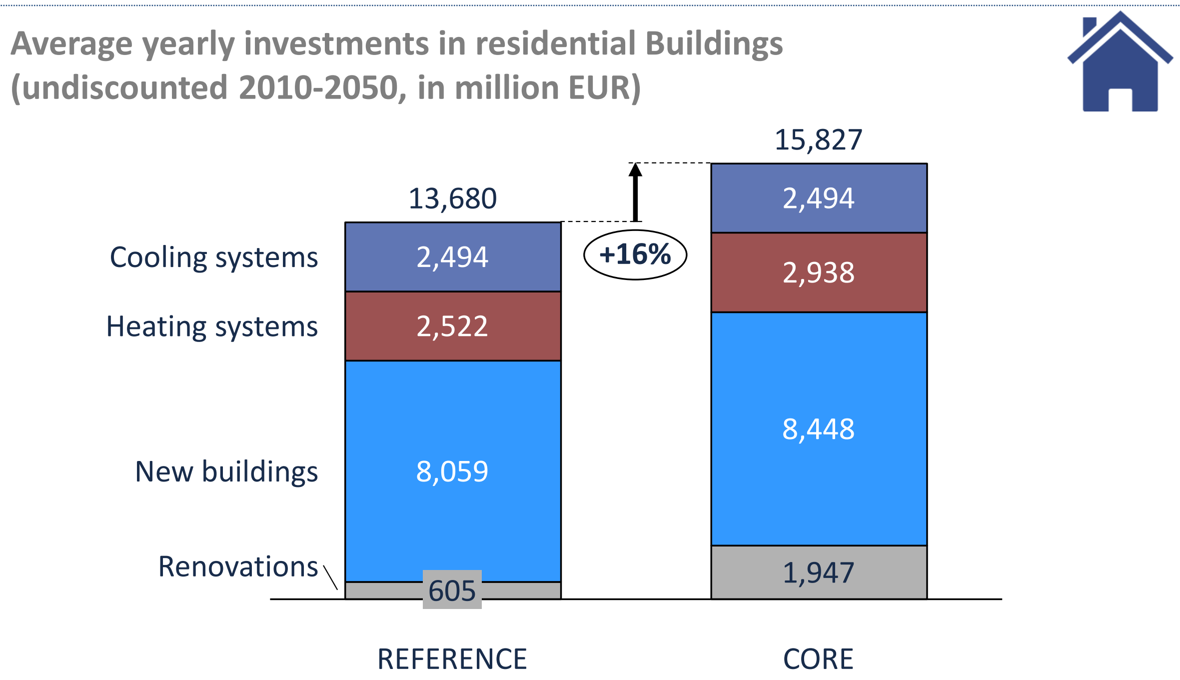


Figure 27. Investment costs in the residential sector.

Barriers

To reach an 80 to 95% reduction target, important barriers will have to be tackled.

The progress towards low energy houses will require investments on the part of Belgian households. Poverty, especially in urban areas, will hamper this evolution. Well-designed financing models should help to tackle this barrier. There is also the need to develop the right instruments to motivate owners to improve the efficiency levels of their properties: today, owners do not have sufficient incentives to renovate their properties, due to the fact that it is not them, but their tenants, who benefit through a lower energy bill.

The awareness and willingness to change behaviour or to invest in efficient technologies must improve. Behavioural changes resulting in lower demand levels (e.g. lower internal temperature) calls for a shift in mindset. The speed of energy efficiency improvements is limited by the number of available manpower in the building sector; the availability of enough trained professionals to operate the transition in buildings must be ensured.

High ambitions will require a system and long-term approach involving all governmental levels and policy domains. Legal competences concerning buildings and GHG emissions are spread between various power levels at EU, federal, regional, provincial and municipality level. A large coordination effort is required between these various entities.

E.3. Industry

Scenario implications

While transport and buildings experienced a rise in GHG emissions between 1990 and 2010, industry emissions strongly decreased over the same period, partly due to an overall decline in activity levels. Continued energy efficiency and fuel switching can contribute to some extent to a further reduction of GHG emissions. However, in order to reach reductions in the order of magnitude of 80% or more, new low-carbon processes and the application of CCS will be necessary in many scenarios except in the BEHAVIOUR scenario where no CCS is required, but where sectors other than industry are stretched extensively.

GHG emissions in industry are lowered by 67% (in the BEHAVIOUR scenario) to 107% (in the -95% GHG scenario) by 2050, with respect to 1990 GHG emission levels (the negative emissions in industry in the TECH scenario are the result of using both biomass and CCS). Figure 28 shows GHG evolution in the various sectors, according to the CORE scenario. With such large reductions in some sectors, great care must be taken to avoid any risks of carbon leakage: the reality of global competition must be recognized and the impact on competitiveness must be regularly assessed and monitored.

The table below shows the percentage reductions reached in each of the scenarios.

Direct GHG reduction in industry compared to 2010 (1990) including biomass impact	REF	CORE	BEH	TECH	-95%	EU Integration
Total	-7% (-27%)	-76% (-82%)	-58% (-67%)	-83% (-86%)	-109% (-107%)	-86% (-89%)

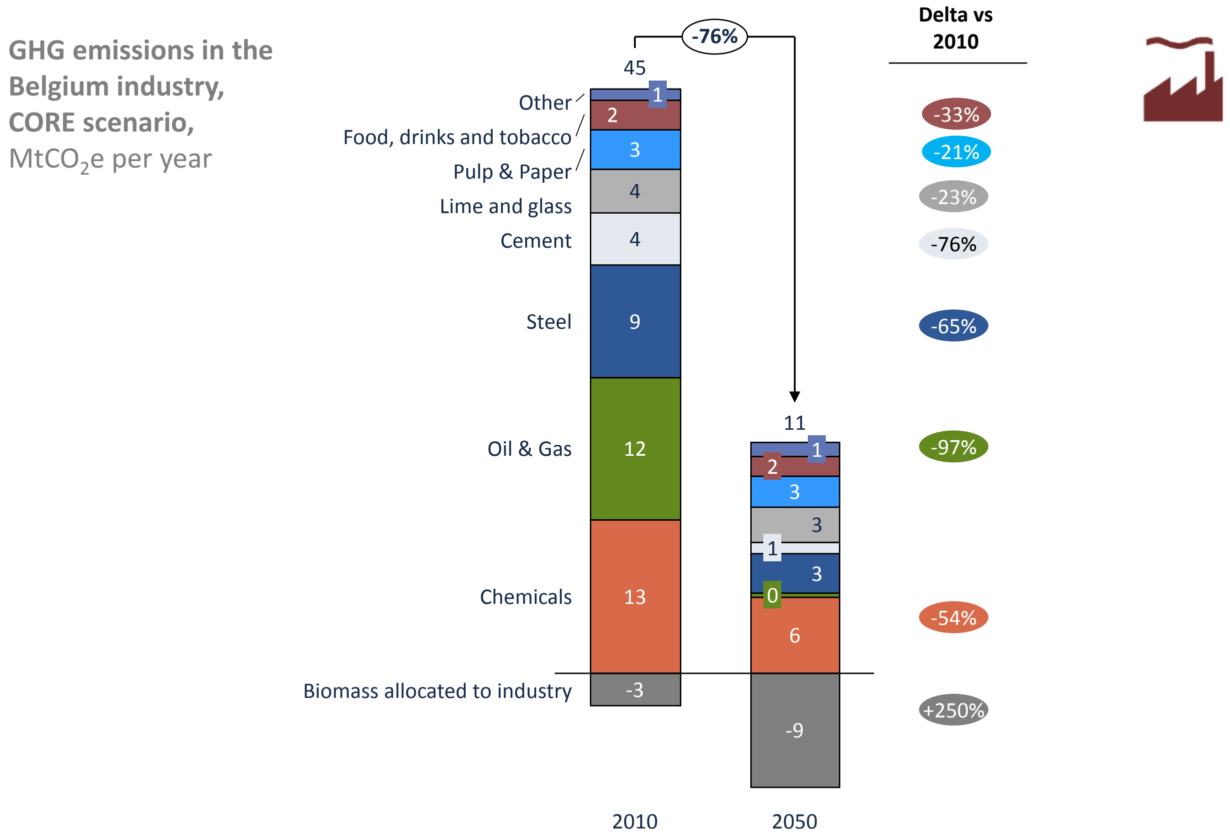


Figure 28. Evolution of industrial GHG emissions per sector in the CORE scenario.

Figure 29 shows the impact of 'behavioural' and 'technical' levers on emissions in the industrial sector. Keeping all technical levers constant (i.e. implementation of energy efficiency, fuel switching and process improvements) compared to the REF scenario while switching all behavioural levers to level 4 (as defined in the BEHAVIOUR scenario – cf. Section D1) has an impact on the food processing sector and the output of the Belgian refineries, reducing emissions by 24% compared to the 2050 REF level.

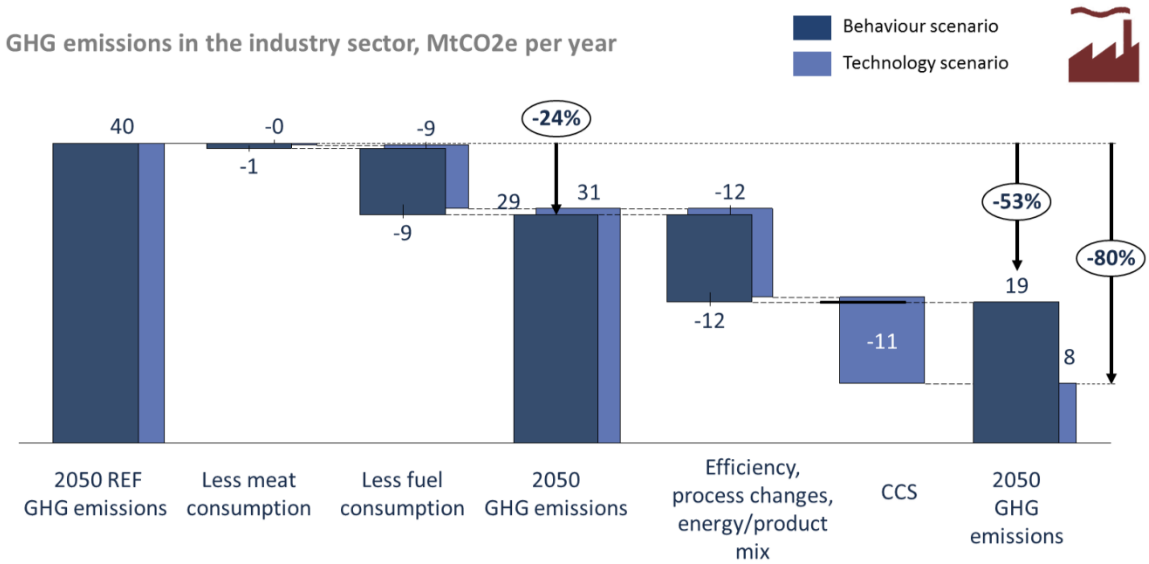


Figure 29. Impact of various levers on Industry emissions in the BEH and the TECH scenarios.

Mainly through the application of CCS in industry, the TECH scenario reduces GHG emissions in industry by 80% compared to the 2050 REF while the BEH scenario reduces these emissions by 53% (both compared to 2050 REF GHG emissions).

Figure 30 shows the level of CCS applied in each of the scenarios. The main rationale is as follows:

- level 1: no application of CCS in industry (BEH scenario);
- level 2: application of CCS on industrial installations emitting more than 1 $MtCO_2$/yr (CORE scenario);
- level 3: application of CCS on industrial installations emitting more than 0.3 $MtCO_2$/yr (TECH scenario);
- level 4: application of CCS on all industrial installations (-95% GHG scenario).

Number of ETS installations and emissions per industry and per installation size

Industry	Number of sites by size			Emissions
	<0,3 Mt	0,3-1 Mt	>1 Mt	MtCO2e
Bricks & ceramics	33			**0,5**
Cement	2	2	2	**4.2**
Chemicals	50	3	2	**6.9**
Food	49			**1.5**
Glass	9	1		**1.1**
Lime	3	2	1	**2.7**
Non-ferrous metals	13			**0.4**
Pulp & paper	1			**0.1**
Refineries	4	1	2	**5.9**
Steel	28	4	1	**6.8**
Others	39			**0.4**
Total	231	13	8	30.6
Total ($MtCO_2e$ (%), 2010[1])	**9 (29%)**	**6 (20%)**	**16 (51%)**	**30.6**
	-95% scenario	**Technical scenario**	**Core scenario**	

Increasing CCS application

1 Actual CCS application in the scenarios will lead to lower capture in later years as these are applied after other levers

Figure 30. Number of CCS sites according to the modelled scenarios.

Refined rules have also been defined for a series of industries (Chemicals,[63] Pulp & Paper,[64] Refineries[65] & Steel[66])

Costs

Figure 31 illustrates the costs brought by the transition in the different industry groups. The more an industry is supported by the transition, the more product demand it has and the higher its fuel and investments costs. In the CORE scenario, investment costs increase, while fuel costs decrease, leading to an overall decrease in total costs of about 19%. Compared to the 'core' scenario, overall costs in the 'behaviour' scenario are still lower (by 4%) because of lower production levels in the refineries and food processing sector. The cost increase in the TECH scenario (compared to the CORE scenario) is mainly caused by the additional application of CCS.

[63] For olefins, CCS is applied only in level 4 on the crackers; For Ammonia & Hydrogen, CCS is applied from level 2 on process emissions; For other ETS installations, CCS is applied following a similar rationale (for level 3 on installations larger than 1$MtCO_2$/yr and for level 4 on installations larger than 0.2$MtCO_2$/yr).

[64] CCS is only applied to the Kraft pulping process in combination with gasification of black liquor.

[65] CCS is applied to all installations as of level 2.

[66] CCS is applied from level 2 to all reduction process emissions, from level 4 to all installations.

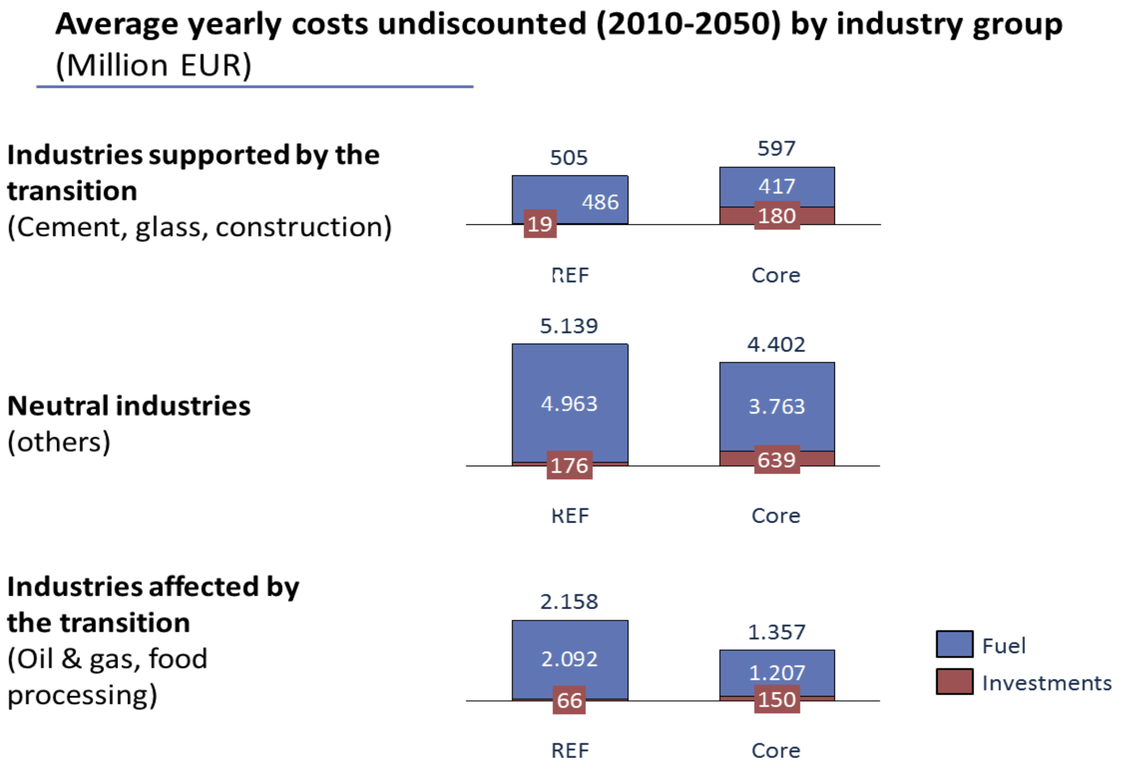


Figure 31. Undiscounted cost in the Industry sector.

Most neutral sectors (steel, lime, glass, pulp & paper) experience a slight increase or decrease (+/- 10%) in total undiscounted costs over the period 2010-2050. A cost decrease is most pronounced for food processing (-22%) and refineries (-46%), which can be explained by the loss of production as they are affected by lower meat and fuel consumption in the low carbon scenario. The Chemicals sector also experiences a strong decrease in costs (-22%), as a site efficiency potential of 20-30% (depending on the type of production) was identified at a negative cost of -40 Euro/tonne CO_2 reduced. These general costs for industry cover the different technical measures envisaged for all of the sectors modelled.

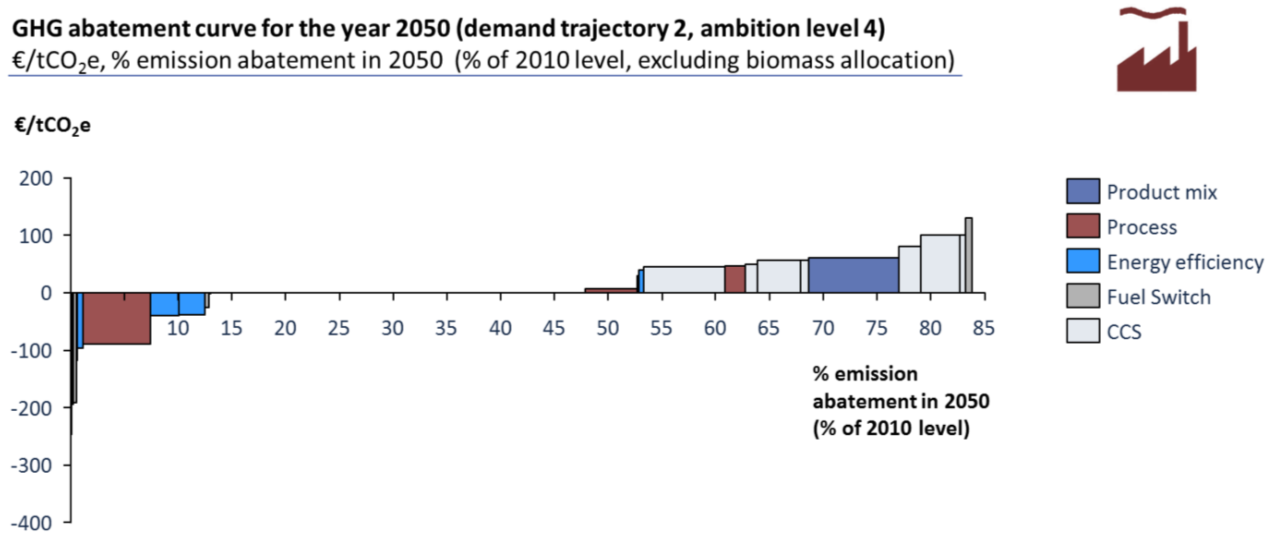


Figure 32. Abatement Cost curve for the industry sectors for 2050.

The MAC summarizes our estimate of the realistic volume and costs of opportunities to reduce GHG emissions in industry. Each rectangle on the curve represents a different opportunity to reduce greenhouse gas emissions. They are grouped into different categories: product mix changes, process changes, energy efficiency improvements, fuel switching and application of CCS (cf. colour codes in Figure 32). The width of each box represents the emissions reduction potential that the opportunity can deliver in 2050 compared to the 2010 baseline. And the height of each box represents the average cost of abating one tonne of CO_2e through that activity.

The graph is ordered left to right from the lowest cost to the highest cost per opportunity. The opportunities that appear below the horizontal axis offer the potential for financial savings even after the upfront costs of capturing them have been factored in. Opportunities that appear above the horizontal axis are expected to come at a net cost. We want to remind the reader however that the costs identified above are not discounted so that they do not necessarily address the private profitability of the investments.

Barriers

Governments have a key role in setting a level playing field to enable industries to act in the interest of the global environment and invest sufficiently in a transformation towards low-carbon industries. However, the role that national climate policy can play is influenced strongly by the global policy frameworks (for climate as well as by trade regulations for instance), the climate policy frameworks adopted at the EU level and by possibly competing domestic policy objectives. An optimal national policy mix to support technical development and cost-efficient mitigation must consider all limitations in the choice of policy instruments that come from global burden sharing principles, free trade, and other policy objectives at the national level.

In particular, Belgian industry is especially focused on exports to the EU as well as global markets, and therefore exposed to competitive pressures. Energy prices have an impact on the competitiveness of energy-intensive industries exposed to international competition; an increase in the price paid for energy by these industries in Belgium and in Europe due to the carbon constraint should be closely monitored in comparison to prices paid in other regions.

Furthermore within the EU, governments can compete for attracting industrial investments by altering governance frameworks (e.g. compensations for indirect carbon leakage). When designing a long-term climate policy for industry, Belgian policy makers should carefully consider the impact of these competitive pressures on Belgian industry, and support level-playing field measures.

One crucial element in the transition to a low-carbon industrial sector in Belgium will be a sufficiently high and stable carbon price (either generated by a market-based instrument such as the EU ETS or by imposing a carbon tax) over a long period of time to send a credible price signal to decision makers in industry. ETS installations are responsible for 84% of industrial emissions in 2010. Investment strategies in these asset intensive industrial sectors generally depend on the cost of existing facilities and the complexity of operations. Core industrial processes change only gradually over the years and the investment cycles in heavy industry are long: in some sectors, 2050 is only one or two major investment opportunities away. Climate policy therefore needs to make clever use of the ‘window of opportunity’ offered by a new investment cycle.

E.4 Agriculture & Waste

Scenario implications

The agriculture sector has a lower emission reduction potential than the other sectors. Various trajectories can abate GHG emissions in agriculture by 38% to 52% by 2050, with respect to 1990.

The table below shows the percentage reductions reached in each of the scenarios (for agriculture only).

Direct GHG reduction in agriculture compared to 2010 (1990) including biomass impact[67]	REF	CORE	BEH	TECH	-95%	EU Integration
Total	+6% (-10%)	-26% (-37%)	-37% (-46%)	-18% (-31%)	-37% (-46%)	-37% (-46%)

In the **REF scenario**, the evolution of the number of animals, the emissions per animal and the total soil emissions are set at the lowest level of ambition. In the **low carbon scenarios**, ambitions are set at the highest level (level 4) in the 'behavioural', '95%' and 'EU integration' scenario. The 'CORE' scenario assumes a level 3 effort. In the 'technical' scenario all ambition levels are set at level 3 except the number of animals (level 2).

As illustrated in Figure 33, lower meat consumption can have a very large impact on emissions, but requires an important shift in behaviour. Other technical measures exist but they currently have a limited impact.

A continuation of the current production system, focusing on productivity gains and food production, has been assumed. However, a systemic approach is needed to attain a resilient and sustainable production system. Such an approach implies that trade-offs or choices have to be made. The agricultural sector should not focus solely on food and feed production but also on other functions, e.g. biodiversity, ecosystem services and bio energy production. The choices made will have an impact both on other economic sectors and throughout the food chain. Further research is needed to better evaluate the GHG reduction potential of the agricultural sector.

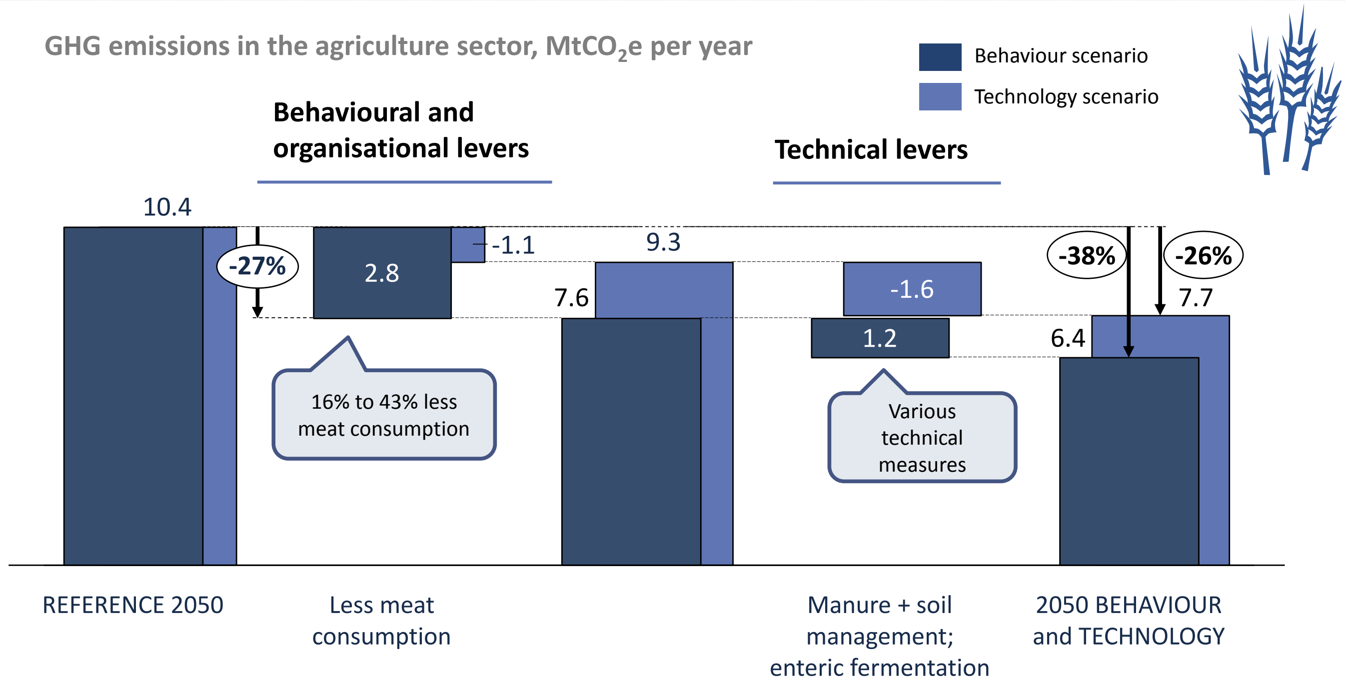


Figure 33. Impact of various levers on Agriculture emissions in the BEH and the TECH scenarios.

67 Does not include combustion emissions in agriculture, nor waste.

Figure 34 shows the impact on the number of animals at level 4, with almost half of the number compared to the reference case.

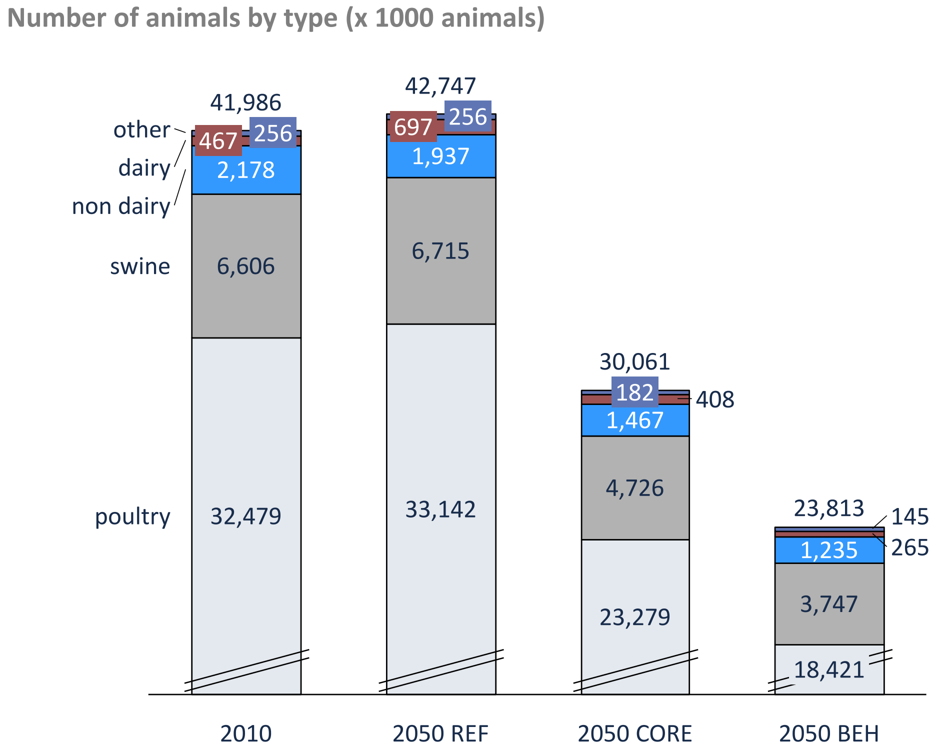


Figure 34. Details of the number of animals in various scenarios.

Costs

We do not take into account costs related to changes in livestock. Based on the study of the Flemish Administration of Agriculture and Fishery,[68] we consider costs (euro per tonne CO2eq) of abatement options (feeding strategy, ration, and additives) to be negligible.[69] Costs of co-digestion are taken into account in the modelling work for bio energy production.

Barriers

The current production system, which focuses on productivity gains and food production, is neither sustainable nor resilient. Food prices are too low compared to other goods and services.

The implementation of some abatement measures will require supporting mechanisms as they are not economically viable.

It is not possible to attain zero emissions in agriculture as a certain level of emissions is intrinsic to nature and to food production. The potential for emission reduction by implementing technical measures, including optimizing ration and increasing productivity, is limited and the optimum will be reached in 2030. After 2030, shifts of paradigms and

[68] Campens V., Van Gijseghem D., Bas L., Van Vynckt I., Klimaat en veehouderij, 2010.
[69] Costs of "technical" measures such as feeding strategy, ration and additives are considered; the impact on farmer income as a consequence of fewer crops or livestock is not taken into account. As not all cost are covered, no conclusion can be drawn about economic viability or affordability.

change of consumer behaviour is needed. Further research to develop and implement new technologies should be encouraged.

Legislation, e.g. the EU Nitrate Directive, could be a barrier to a reduction of N_2O emissions and the creation of carbon sinks as it controls the use and management of nitrogen fertilizers on farms with the primary aim of reducing pollution of surface and ground waters. However, the control on nitrogen fertilizer also has an impact (positive or negative) on emissions of nitrous oxide (N_2O) and thus impact on emissions of greenhouse gases.

E.5 Energy supply

Scenario implications

Reductions in energy demand in all sectors translate into lower energy demand overall. Figure 35 shows the drastic reductions with the Behaviour and Technology scenarios leading to ~30% to ~45% decrease in overall energy demand compared to 2010.

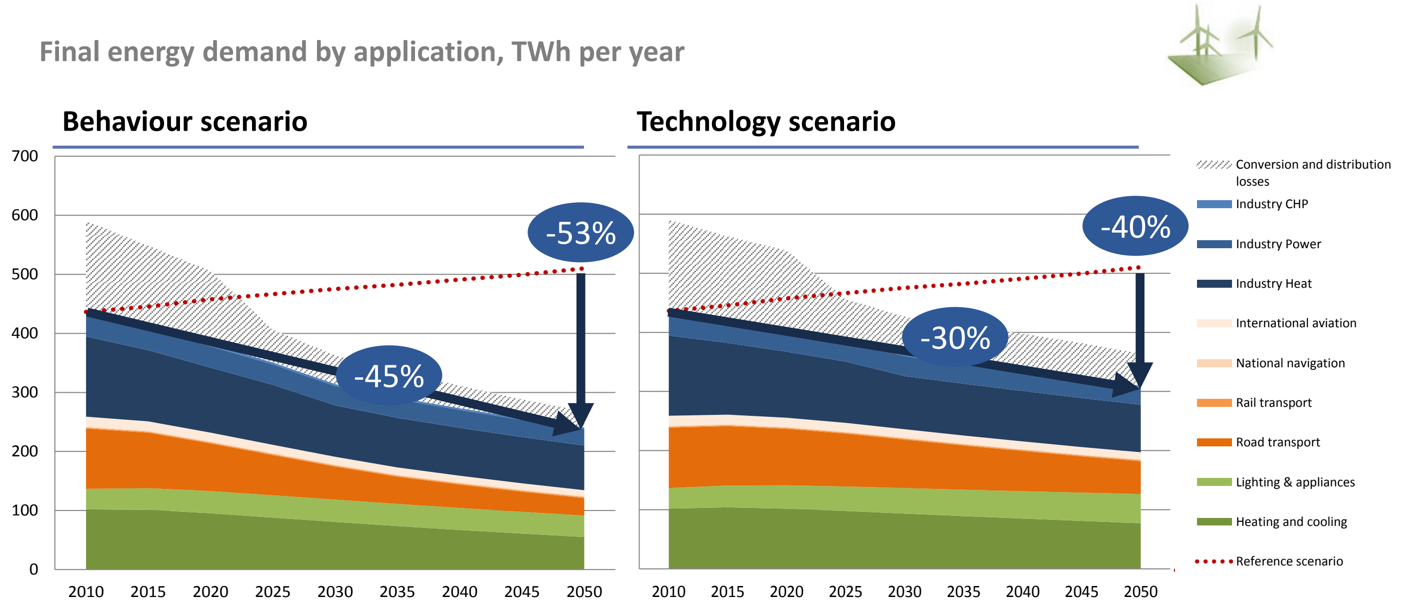


Figure 35. Final energy demand in the Behaviour and Technology scenarios.

The supply mix is also deemed to change, leading to lower carbon emissions. Figure 36 below highlights primary energy supply in the CORE scenario. The level of fossil fuel production drops by 75%, with RES making up much of the supply in 2050.

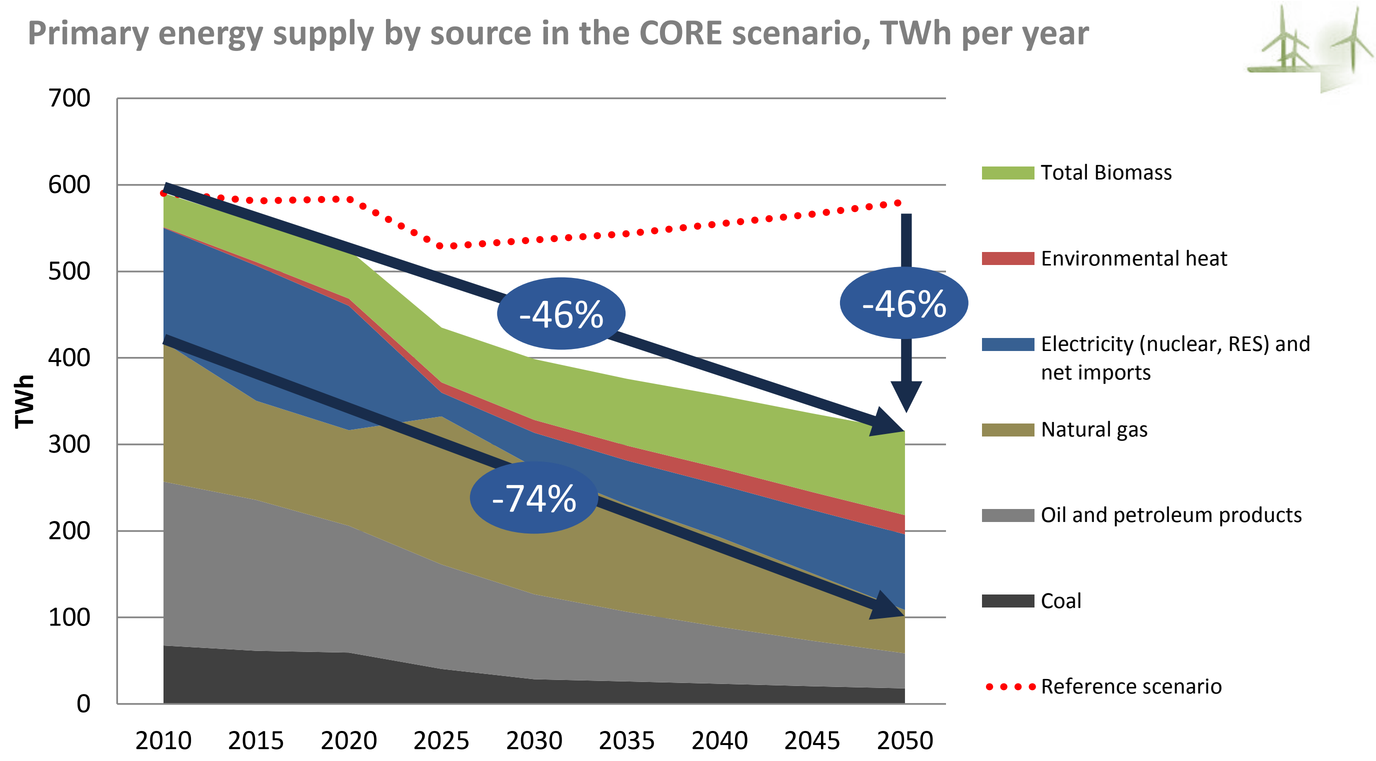


Figure 36. Energy supply in the Core scenario.

Figure 37 compares the energy supply reductions and the mix in 2050 across scenarios. It is clear that any scenario intending to reach at least ~80% reductions in GHG emissions requires massive energy demand reductions. Even the more technology focused scenarios lead to almost ~40% energy supply reductions. We also see a significant shift to more renewable energy supply.

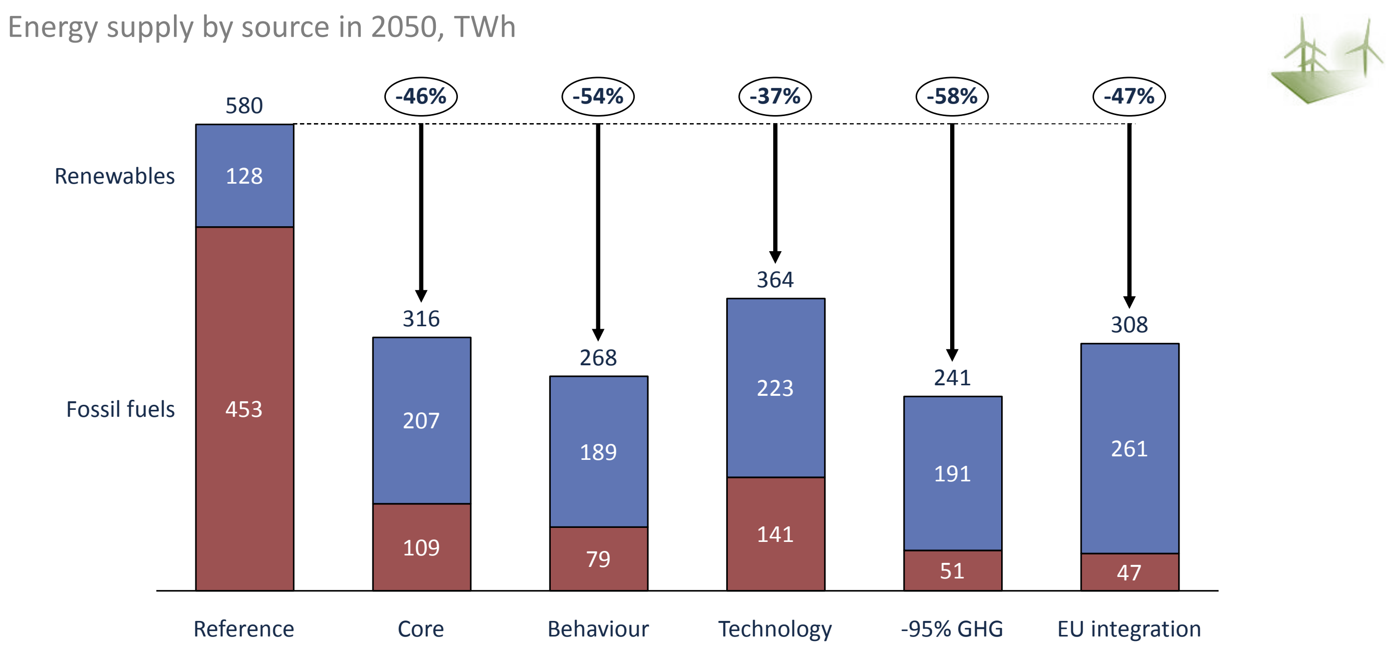


Figure 37. Energy supply in 2050 in each scenario.

Furthermore, the supply itself is also deemed to change and lead to lower GHG emissions. In all scenarios, the share of electricity in the supply mix increases. In the CORE scenario it grows from 20% in 2010 to 37% by 2050 (and to 52%

in the EU INTEGRATION scenario). In absolute terms, total electricity demand rises above its 2010 level by 2050 in all scenarios, except in the BEHAVIOUR and the '-95% GHG' scenarios, where its level remains roughly constant over time.

The electricity sector has to be almost completely decarbonised in order to support decarbonisation in other sectors: to achieve an 80 to 95% GHG reduction, emissions in the transport and the buildings sector have to be significantly reduced, partly through electrification of energy demand.

Figure 38 shows the level of electricity demand and the electricity production mix in 2050 for the various scenarios. By that time, nuclear production has disappeared as per latest federal legislation. Gas plants (without carbon capture and storage) are only found in the REFERENCE scenario and are key as an intermediary source of electricity between 2020 and 2040; they are replaced over time and could potentially be used as back-up.[70]

Intermittent renewable energy sources (solar PV and wind) make up a significant share of the electricity production in 2050 (~50% in the CORE scenario), while non-intermittent renewable energy sources are also key, with biomass and geothermal supplementing the mix and supporting grid stability along with back-up plants.

Lastly, in some of the scenarios, a certain amount of net electricity imports is assumed, with the EU INTEGRATION scenario having the highest imports (almost 10%), by assuming that the European market is fully integrated so that renewable energy that is produced elsewhere in a cheaper way, can be imported. Only in the TECHNOLOGY scenario is a small share of power generation with carbon capture and storage (CCS) assumed.

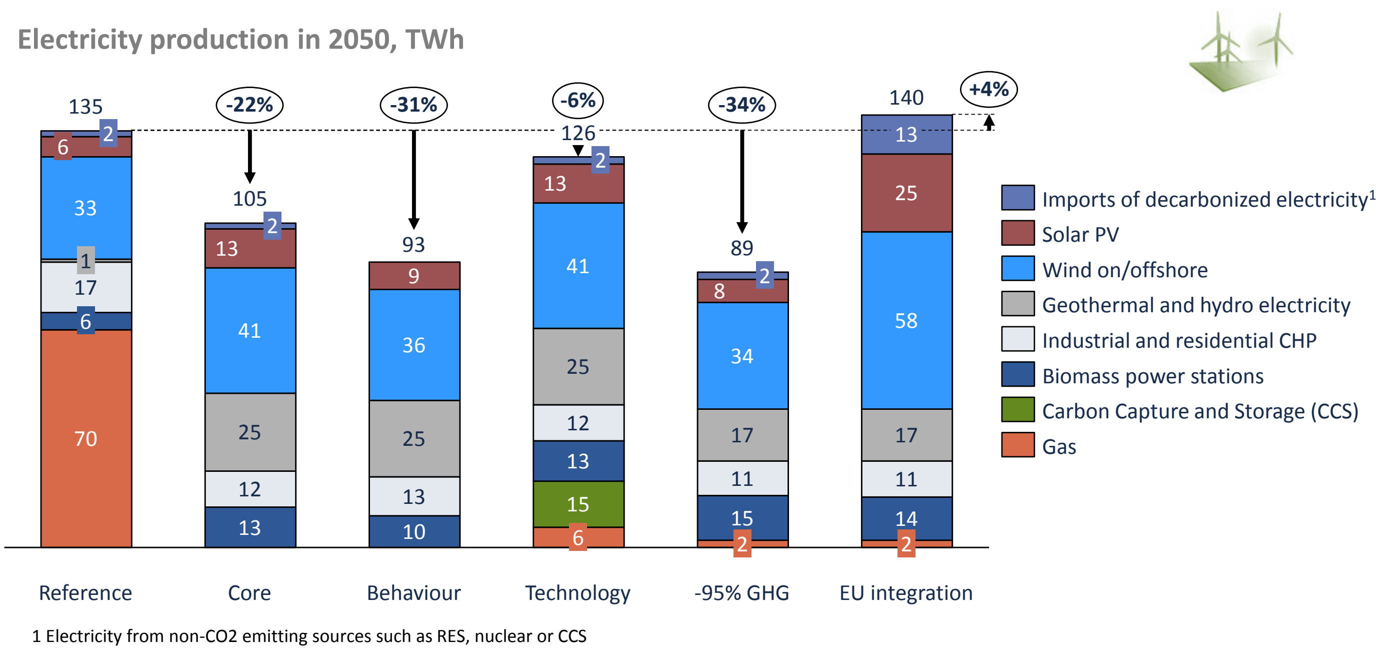


Figure 38. Electricity supply in the various scenario in 2050.

In practice, all scenarios reach very large emission reductions in the electricity sector, as illustrated in the table below.

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[70] This would require an evolution of the electricity market to make these investments profitable.

Direct GHG reduction in electricity production compared to 2010 (1990) including biomass impact	REF	CORE	BEH	TECH	-95%	EU Integration
Total	12% (-6%)	-98% (-98%)	-98% (-98%)	-86% (-88%)	-96% (-97%)	-96% (-96%)

Grids : managing intermittent electricity production sources

The electricity system must be continually balanced to match supply and demand. This section sets out the range of options to ensure the electricity system can operate securely to supply peak demands and manage variations. A range of existing and future technology options are available to meet changing requirements. The transition to new forms of balancing on a low carbon electricity grid will have to be well managed in order to deliver sufficient power, and deliver it reliably.

This is a significant challenge. Energy produced based on intermittent sources (mainly wind and solar) represented ~2% of total electricity production in 2010. The range of modelled scenarios looks at increasing this share up 40-50% in most scenarios, and even up to 60% in a very integrated European network (European integration scenario). These intermittent sources currently contribute very little to power balancing and their lack of flexibility has to be compensated by flexible sources of production. The increasing share of intermittent sources will require new mechanisms to ensure that intermittency is managed properly in the future.

More sources of flexibility will be used in the future. They can be described by the following categories:

- Conventional power plants, like combined-cycle gas turbines,
- Back-up plants, e.g., simple open-cycle gas turbines (OCGT), primarily used at critical times,
- Demand flexibility ('Demand Side Management' or DSM),
- Interconnection to neighbouring countries,
- Energy storage, which can be an alternative to back-up plants.

Our work integrates these various solutions by leveraging the results of the ECF studies performed independently by highly respected consultancies in the field (McKinsey, KEMA, Imperial College London). These studies analyzed the need to develop these various sources of flexibility at the European level by modelling the balancing of demand and supply of electricity hour by hour over a full year assuming large decarbonisation of the power sector. The model evaluates the potential for DSM and storage at the European level. It also estimates the requirements for additional transmission and interconnection capacity, and the need for additional back-up plants in Europe to ensure that balancing is done at least cost.

The results of these studies show that it is possible to integrate a large number of intermittent sources at reasonable additional cost. This requires a large increase in transmission networks at the European level, to ensure that intermittent production is used optimally at the moment it is produced, as well as to reduce demand variability.[71] Extensive development of the transmission network is a fundamental element in the solution, but compared to the

[71] Peaks in electricity demand are less pronounced when summing up the demand of all European countries than for each individual country, due to time and cultural differences.

cost of the actual supply capacity, it represents less than 10%, along with back-up plants which can account for up to 30% of installed generation capacity.[72]

Depending on the scenario, these studies show the need to triple or quadruple our interconnection capacity with neighbouring countries, as well as to build 6 to 10 GW of gas back-up plants (12 to 20 OCGTs of 500 MW).

- Interconnection is key for various reasons. Firstly, it supports security of supply. Secondly, it enables us to buy (or sell) electricity at the best price, here or abroad. Thirdly, it enables us to transport electricity across our networks to ease the imports and exports at various moments of over- or under-production. The increasing requirements for these 3 objectives will be such that interconnection with our neighbours (and to a certain extent transmission networks within Belgium) will need to at least triple the amount of high tension interconnections compared to today. Such a multifold increase is very challenging, particularly seeing the difficulty network operators find to build new large interconnections.
- Back-up power plants will also play a key role to ensure a sufficient level of security of supply. They will represent a large share of electricity production capacity in Belgium: above the 30 to 40 GW of capacity required for production, another ~7 will be required as back-up to balance the system. These back-up plants would represent 5% to 15% of total costs in the electricity sector. These plants will serve mainly to secure capacity and will produce little electricity, which means that remuneration systems will need to be revised to ensure they are profitable.

Figure 39 illustrates the profile of the electricity capacity and backup necessary to cope with intermittency.

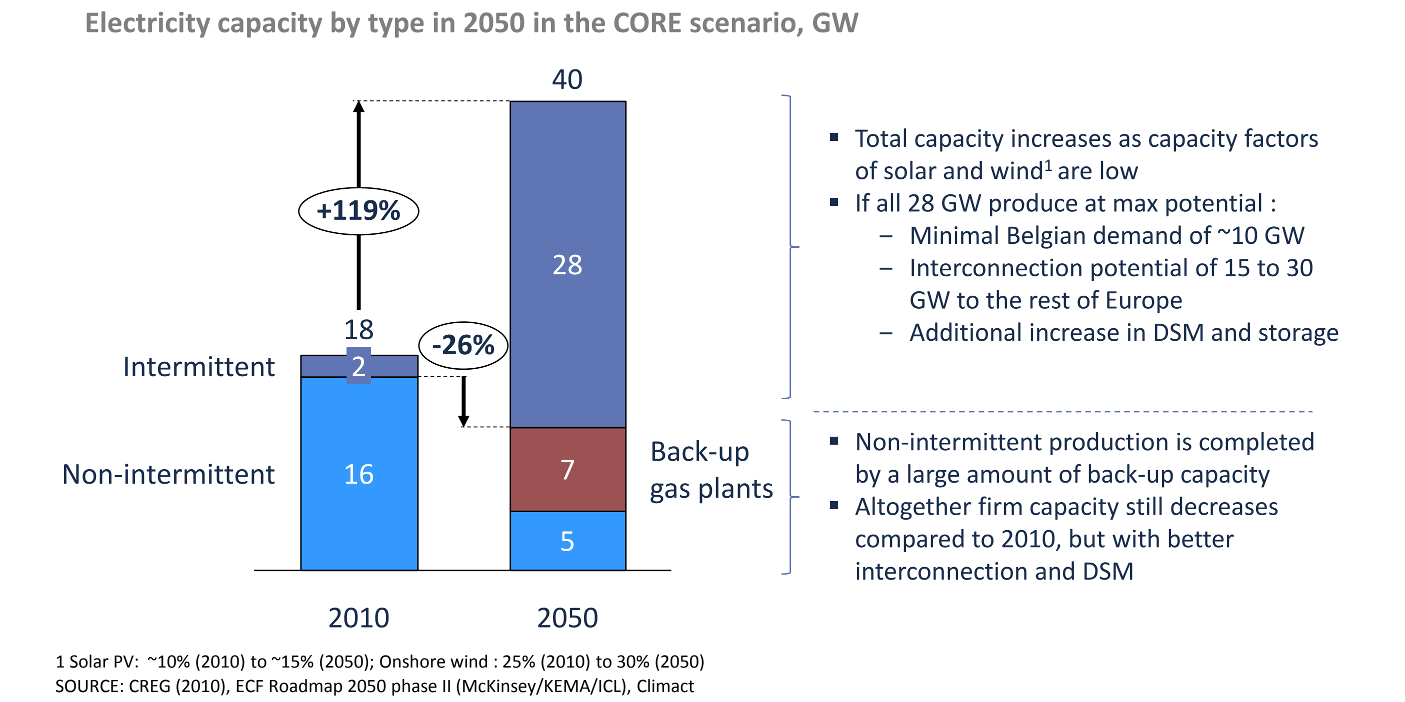

Figure 39. Electricity capacity and backup.

Demand side management (DSM) will play an important role in limiting interconnection and back-up requirements. The development of a 'smart grid' will capture a large amount of flexibility available at the consumers' level. DSM could contribute to a reduction of 25 to 40% of additional transmission and back-up requirements described above.

[72] For a more detailed description of these challenges we encourage the reader to read the full report from the ECF Roadmap 2050 work available at www.roadmap2050.eu .

However, it is still early to estimate the exact flexibility available at the consumer level. Additionally, direct costs for these solutions are relatively well estimated, but indirect costs are hard to evaluate: consumers will need to implement part of the flexibility solutions at home.

Optimal solutions from the European analysis highlight the strategic geographic situation of Belgium. The optimal solution in a European perspective is clearly to massively increase transmission capacity in Belgium to allow for large electricity transfers through our country. Belgium would therefore become an electricity transmission hub at the European level. This choice could be an opportunity for Belgium, supporting employment through the construction, maintenance and exploitation of back-up plants and transmission lines, but at the same time it is a challenge in terms of the use and protection of natural habitat.

Costs

Costs in the energy sector (including fossil fuel imports) are largely driven by the amount of energy required, as well as by the energy mix of each of the scenarios.

All decarbonised scenarios have significantly lower final energy demand than the reference scenario (Figure 37), logically combined with significantly lower fuel costs as seen in Figure 40. However, capital costs are higher than in the reference case, particularly as investments in the electricity sector are higher (see more detailed information below).

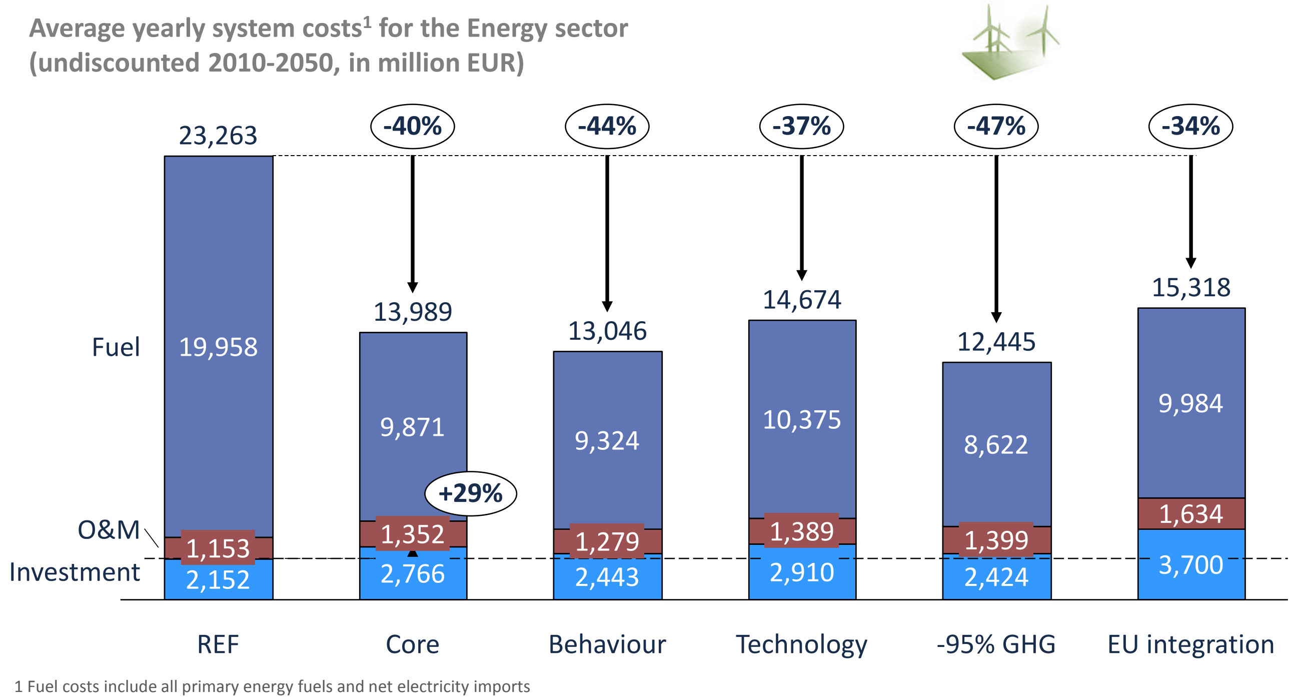

Figure 40. Average yearly cost in the energy sector across scenarios.

Due to significant electrification of demand sectors, the reductions are lower in terms of electricity production, and some scenarios even have higher consumption than the reference one. For example, the EU integration scenario has ~10% higher electricity demand, as highlighted in Figure 38, and also has ~11% higher total electricity costs (Figure 41). The Behaviour scenario has 36% lower electricity consumption, but its costs levels are only ~22% below the reference case due to a slightly more expensive energy mix.

All other scenarios find themselves between these 2 extremes, but apart from the EU integration scenario, all of them are below the reference scenario. This highlights the importance of energy efficiency leading to lower final energy demand, where lower fossil fuel demand compensates higher investments costs.

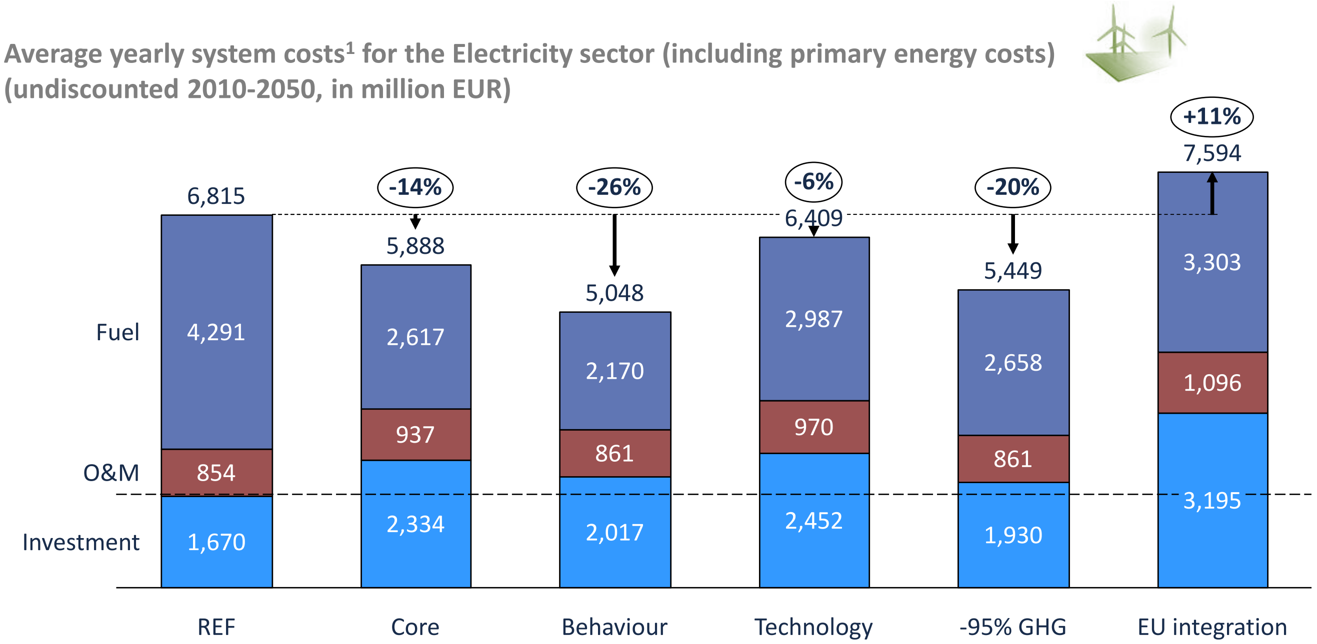

Figure 41. Average yearly cost in the electricity sector across scenarios.

The investment part of this cost is higher in all low carbon scenarios compared to the reference scenario. Figure 42 breaks down these investments by type across scenarios.

The electricity sector is also one of the most important in terms of investment requirements in the energy sector: in the EU integration scenario, larger solar PV and wind capacities lead to higher investments costs, and higher electricity imports together with large biomass-based electricity production lead to high fuel costs.

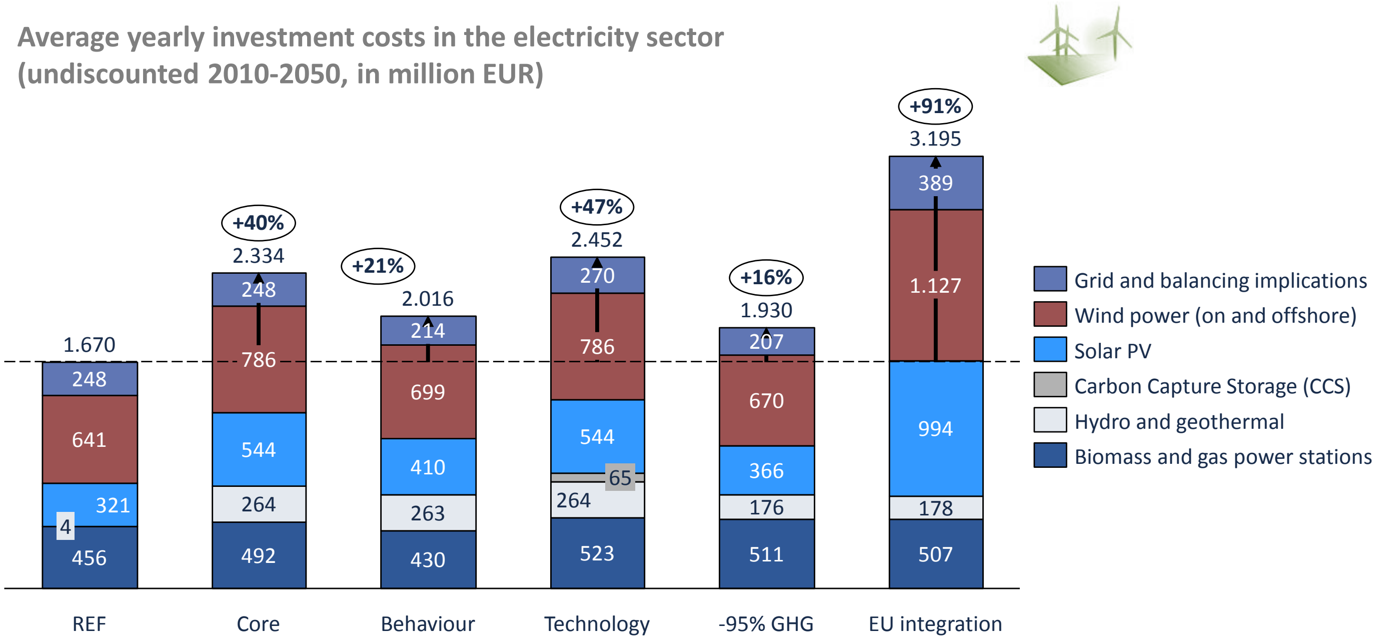

Figure 42. Average investment cost in the energy sector across scenarios.

Barriers

Barriers for the decarbonisation of the energy supply are manifold and vary depending on the supply component. Biomass is limited by restrictions considering sustainable supply and competing uses, intermittent sources face the NIMBY public acceptance factor, CCS is uncertain and also faces public resistance, etc.

Barriers for the implementation of grids are also well-known, mostly including the resistance of local population to seeing new power lines run through their neighbourhood. NGOs as well as transmission network operators are currently working together to try to reduce the complexity of deploying new transmission capacity.

F. OVERALL IMPLICATIONS

Europe is committed to 80% to 95% GHG emission reduction in 2050over 1990, and it is crucial for Belgium to better understand the technical feasibility and the implications of such European targets. Belgium would need to increase by almost 5 times the level of yearly GHG reduction in order to achieve this range, compared to the reduction level from 1990 to 2010. This requires a paradigm shift towards a low-carbon society and public acceptance. Furthermore competitiveness/carbon leakage issues have to be managed as the transition will imply massive changes. The scenarios analysed in this study must be understood in this context.

F.1 Implied trajectories on key variables

Previous sections have highlighted a set of scenarios that explore some of the most important alternatives Belgium has when decarbonising to significant levels by 2050 and beyond. This section uses these scenarios to highlight the required reductions as potential ranges.

Figure 43 illustrates the legend of the following graphs included in this section.

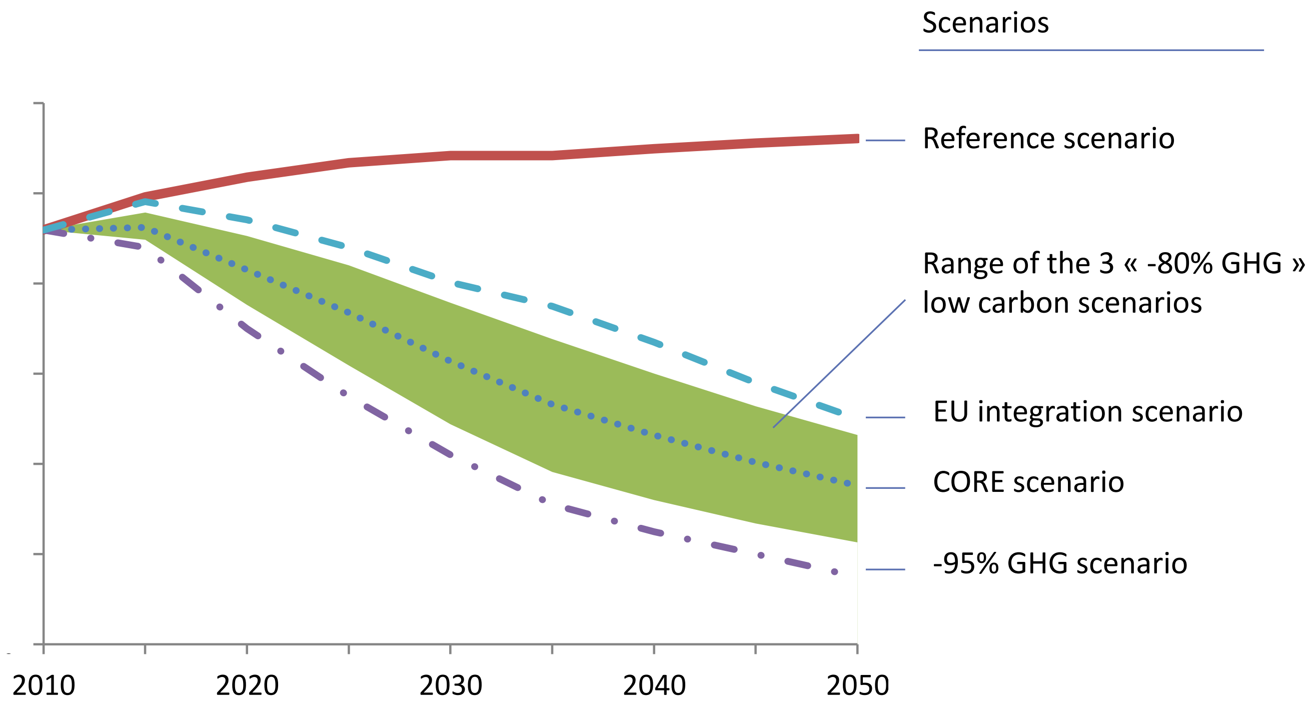

Figure 43. Legend of the figures on implied trajectories.

Lowering energy demand is the key and the electrification of remaining demand supports decarbonisation

Energy efficiency is identified by many experts as the key driver for sustainable energy use. This study goes beyond this finding and adds a significant range of changes both in personal behaviour and in the organisation of society.

It shows how the combination of energy efficiency and changes in behaviour and societal organisation can lead to major reductions in energy demand. There is a large untapped potential in all demand sectors, especially in the buildings sector.

Figure 44 and Figure 45 illustrate the significant energy reductions in all low carbon scenarios compared to the REFERENCE scenario. All three "-80% GHG" scenarios lead to significant reductions. Even the more technology-focused scenario leads to almost 40% energy demand reductions compared to the reference case (-30% vs. 2010).

The EU integration scenario falls within the reductions range of the three "-80% GHG" scenarios. Although behaviour and societal organization levers are left at the same level as the reference scenario, this is compensated by a stronger focus on energy efficiency and electrification, both at level 4, to support lower energy consumption. Once again, this highlights that various pathways exist to reach similar outcomes, but leaving aside one dimension requires going very far into another.

The "-95% GHG" scenario highlights the level that can be reached by pushing all levers very far, up to ambition level 4. This leads to a maximum reduction, effectively cutting in half the 2010 energy demand.

Figure 45 also shows that despite serious reductions in final energy demand, electricity is at best stabilized and likely increases up to 50% compared to 2010, highlighting how transport and buildings (and industry sectors to some extent) are likely to be massively electrified, along with a growing demand in small appliances (e.g., electronics). Combined with a decarbonised electricity production, this supports effective decarbonisation.

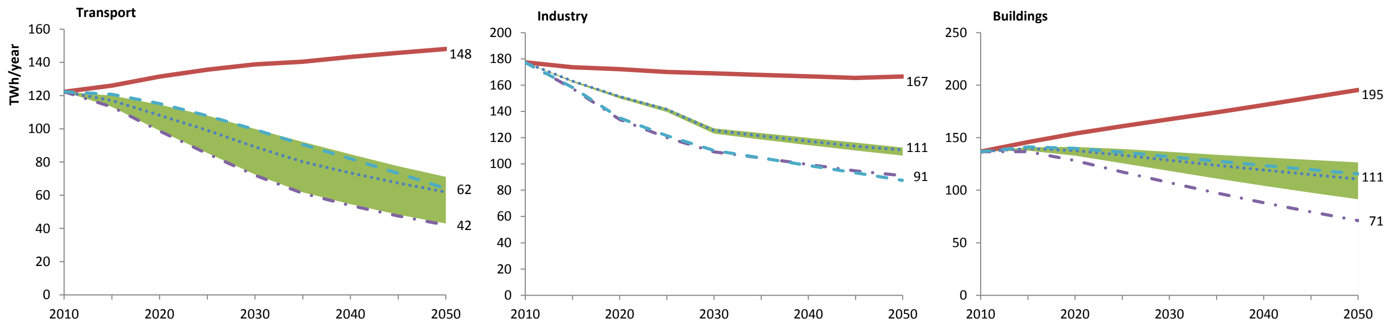

Figure 44. Final energy demand in the 3 main demand sectors in the various scenarios.

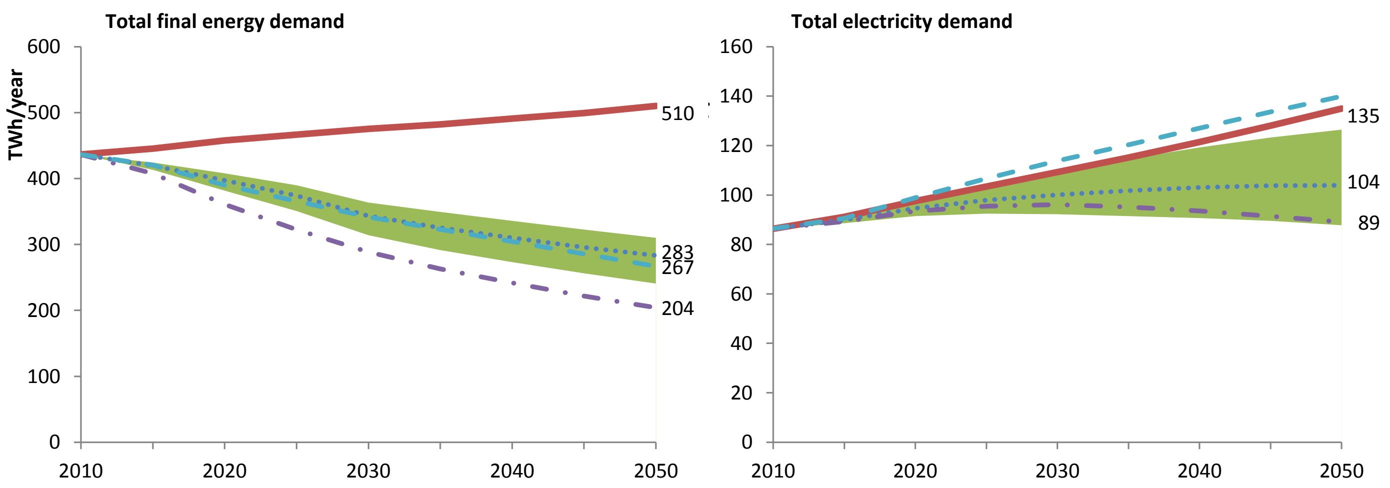

Figure 45. Final energy and electricity demand in the various scenarios.

Fossil fuels are drastically reduced and renewables increase manifold

Together with large energy demand reductions, energy supply needs to undergo a complete reconfiguration. The consumption of fossil fuel-based energy would have to drop to reach significant GHG emission reductions. Figure 46 shows how fossil fuel imports would consequently be reduced by 70% to 85%.

At the same time, energy production from renewable energy sources will need to increase, reaching by 2050 a level four times higher than in 2010. Still, only 12.5 TWh need to be produced based on PV panels by 2050 in the CORE scenario while their technical potential is estimated at over 40 TWh. Similarly, the production of wind energy reaches 19 TWh, compared to a potential of ~30 TWh. The deployment levels of non-intermittent renewables such as biomass and deep geothermal energy is set to level 3, and is therefore closer to their respective technical potential.

It is worth noting the increase in fossil fuel use after 2020 when the remaining nuclear reactors are scheduled to be shut down. It is assumed that gas-fuelled power plants will replace this production in the short term, before being replaced over time by RES or CCS.

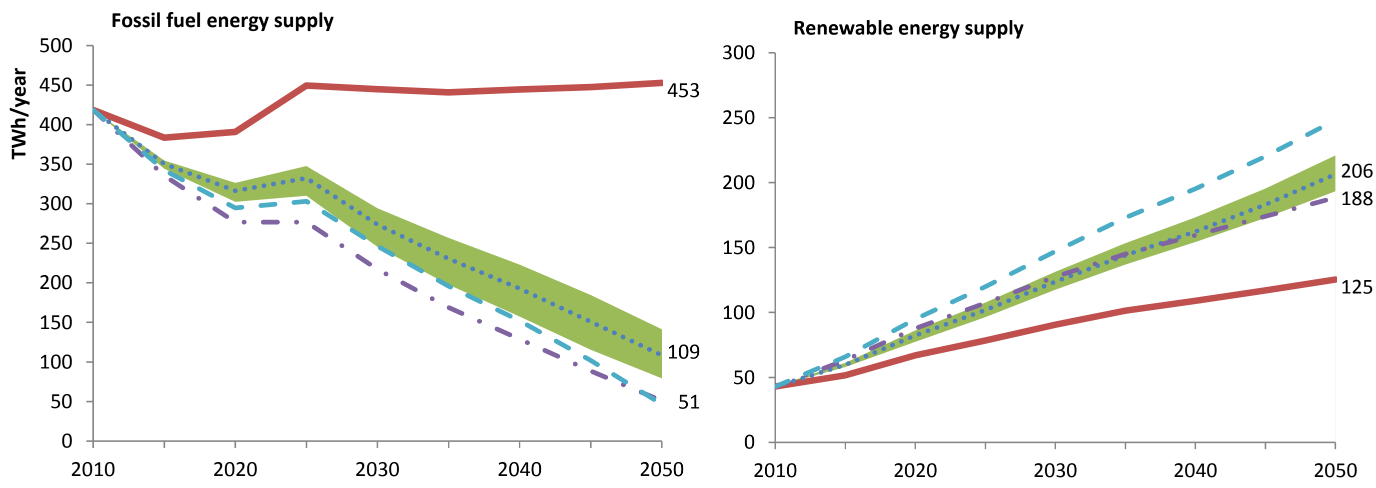

Figure 46. Fossil-fuel and renewables based energy supply in the various scenarios.

Sustainable biomass is likely going to be important for the low carbon transition. Carbon capture and storage could also play an important role but concerns regarding its feasibility and potential risks have been raised.

Bioenergy is already part of the energy supply of some sectors. While sustainability criteria need to be refined further to ensure they effectively support a sustainable low carbon transition, they will play a key role in the transition, supporting the reduction in fossil fuel needs. Indigenous sources need to be better exploited, and imports will complement this potential.

Biomass is a flexible, however limited, resource. There is likely to be further competition for biomass resources globally and from a number of other sectors such as food and paper. This study considers biomass for energy always as secondary to food and direct uses.

Utilisation of both domestically produced and imported bioenergy requires careful monitoring of many impacts, such as the impacts of direct and indirect land use change, the effects on local livelihoods and natural ecosystems and the impacts on global food prices. Including sustainability criteria in the assessment of biomass potential for energy is therefore of crucial importance. Even with the use of sustainability criteria, estimations of worldwide available bioenergy vary significantly. The level of maximum imports used in this work is based on the estimated maximum sustainable amount of biomass production worldwide. This potential is equally distributed per person worldwide. This leads to a potential of 80 to 120 TWh for Belgium in 2050 (including ~34 TWh of indigenous production). This potential is tapped significantly in almost all decarbonisation scenarios (see Figure 11-left).

Carbon capture and storage (CCS) could be applied both for power production and large industrial plants. At the moment, it is one of the only large scale solutions in development to reach substantial reductions for large industrial

GHG emitters. However, it is currently experiencing delays in its anticipated development and concerns regarding potential leakage of the carbon stored have also been raised. Figure 47-right shows that it would be technically feasible to reach 80% GHG reductions by 2050 without CCS (the BEHAVIOUR scenario has no deployment of CCS), but this would require increasing the ambition level in other sectors substantially. In the CORE scenario, 9 MtCO_2e would be abated per year by 2050 based on CCS, effectively covering 8 large industrial sites.

It is also worth bearing in mind that much larger reductions are required beyond 2050 to stay on a maximum +2°C pathway. Combined with biomass, CCS could make negative emissions reachable, and become one of the elements of the transition in the long term if no alternative solutions emerge.

This said, significant technological uncertainties remain. While our work focuses on technologies that are largely proven or in advanced development, it is not possible to predict how the technological landscape will develop in the next 40 years and surprises, probably both positive and negative, will occur. Innovation, non-technical as well as R&D, would facilitate the transition and need to be encouraged.

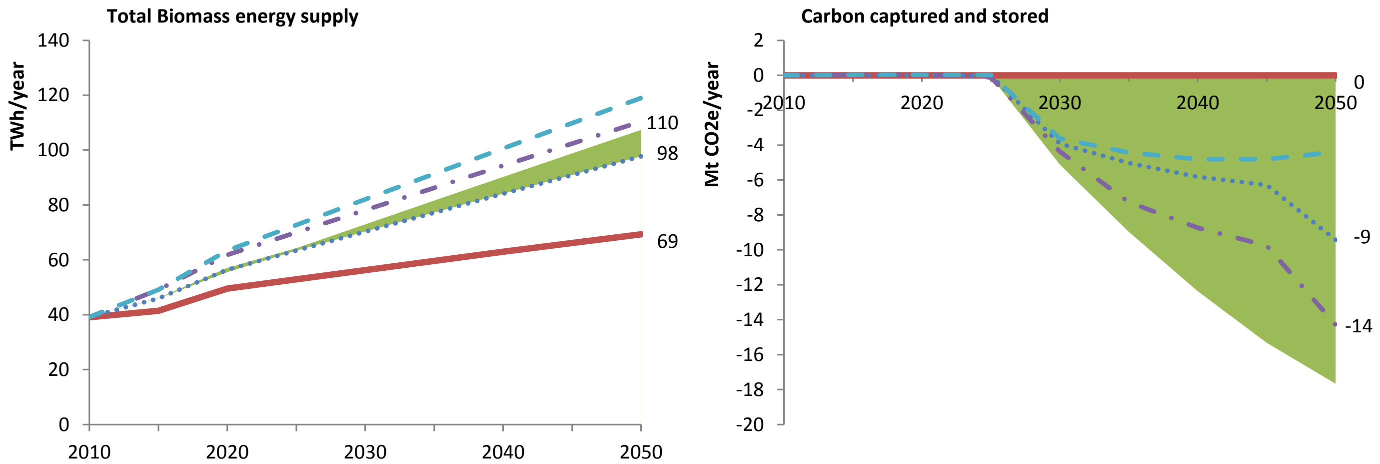

Figure 47. Bioenergy supply levels and CCS deployment in the various scenarios.

Intermittent energy sources will increase significantly, are manageable, but require large interconnection, back-up and demand-side management measures.

In view of the need for higher decarbonised electricity supply, the nuclear phase-out and the uncertainty surrounding CCS, other low carbon technologies will be required. Several RES options are available, and the indications are strong that their deployment potential is significant. Yet all of them have their downsides : sustainable indigenous or imported biomass is limited, electricity from geothermal sources is still expensive and the Belgian potential is uncertain, hydro potential in Belgium is very limited, onshore wind requires public acceptance, and just like offshore wind and solar, it is intermittent.

The share of intermittent energy sources, such as solar and wind, will increase in all scenarios, even in the REFERENCE scenario (see Figure 48-left). In most scenarios, the level of intermittency reaches 40 to 50%. In the EU INTEGRATION scenario however, the higher level of interconnection with neighbouring countries can raise the level of intermittency up to 60%.

Solutions exist to ensure that intermittent sources do not affect security of supply. Demand-side management will play an important role in limiting the need for interconnection and back-up installations; it could contribute to a reduction of 25 to 40% of additional transmission and back-up requirements. The development of a smart grid will capture a large amount of flexibility that is available at consumers' level. The back-up capacity amounts to 7 GW in 2050 in the CORE scenario (see Figure 48-right), to be compared to the overall installed capacity of ~50 GW, of which about two thirds are intermittent (wind and solar). Interestingly, the reference scenario has similar back-up requirements because of its significantly higher power demand, even though it requires less back-up capacity per TWh.

Several European analyses highlight the strategic geographic situation of Belgium. From a European perspective, the optimal solution requires an increase in transmission capacity in Belgium to allow for electricity transfers between European states. Belgium would therefore become an electricity transmission hub within Europe. This option could be an opportunity for Belgium, by supporting employment through the construction, maintenance and exploitation of back-up plants and transmission lines. However, at the same time this solution could be a challenge in terms of use and protection of our natural habitat.

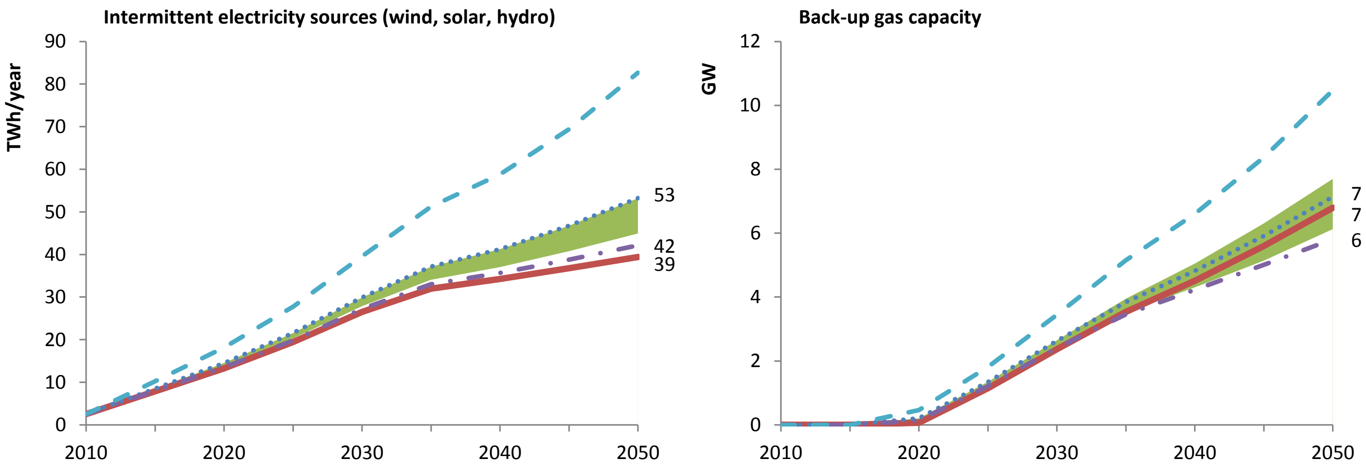

Figure 48. Electricity from intermittent sources and standby capacity in the various scenarios.

F.2 Overall system cost implications of the low carbon transition

We refer to section "Costs" for a detailed overview of the cost methodology. As described in that section our analysis focuses on the following system costs: capital expenditures (including infrastructure costs), fixed and variable operating costs, and fuel costs. It is important to again highlight that providing a comprehensive estimate of the costs of decarbonisation out to 2050 is very challenging: no one can predict accurately how fuel and technology costs will develop over such a long period.

The analysis focuses on the following energy system costs: capital expenditures (including infrastructure costs), fixed and variable operating costs and fuel costs. Similar to the conclusion from the European 2050 Energy roadmap, this work finds that total system costs do not increase significantly in a low carbon economy. It shows that, in the three scenarios leading to reductions of 80% and in the -95% GHG scenario, the costs in the low carbon scenarios are similar to those in the REFERENCE scenario (see Figure 49). Interestingly, total additional investment costs required for the low carbon transition are set off by gains from the reduction in fuel expenses. In the EU INTEGRATION scenario however, costs are higher. This reflects the particularly low ambition levels assumed for some of the key demand drivers in this scenario, particularly for transport where there is no transport demand reduction and no shift to softer transport modes.

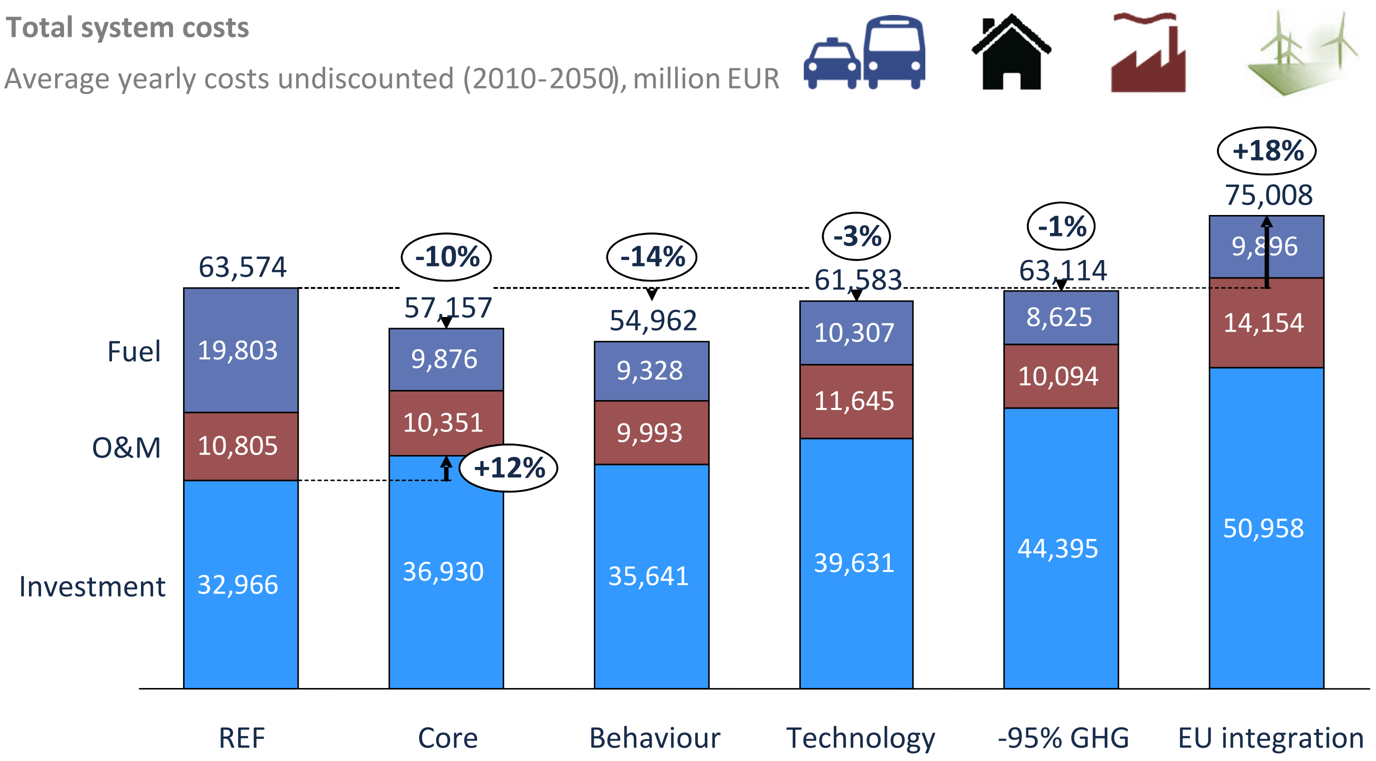

Figure 49. Average yearly system cost across scenarios.

However, real conclusions are best drawn at the sector level, as the magnitude of cost differs vastly. This is explained in more detail in the section on sector implications. It is clear that transport and buildings weigh significantly in the cost figures.

In the transport sector, the shift from investments in individual transport (e.g. buying cars) to investments in collective transport (e.g. buying buses and trains) results in lower overall investment requirements in this sector in the low carbon scenarios than in the REFERENCE scenario. In the buildings sector, the investments associated with the deployment of heat pumps account for the major part of the costs. In Industry, total costs in the CORE scenario are no higher than those incurred in the REFERENCE scenario, at least not in the sectors where production is not affected by the low carbon transition. In the energy supply sector, with a supply mix based on more fixed costs, investments increase drastically in the electricity sector, while fuel costs decrease massively.

The analysis does not prioritise scenarios on the basis of their respective costs: a comprehensive cost-benefit or cost-effectiveness analysis is beyond the scope of the study as it would require complementary analyses to assess many other impacts. Its aim is to give an indication of the magnitude of the investments required and an idea of where these investments are needed. Another aim is to raise the critical issue of how to mobilise resources to finance these investments: the transition implies early investments financed by later fossil fuel economies and puts the question of financing at the heart of the debate.

Further work is also recommended on understanding the implications of a low carbon transition for electricity price settings, both for businesses and private consumers.

F.3 Sensitivities

Sensitivity to fossil fuel prices

Moving to a low carbon economy would reduce the exposure to high fossil fuel prices, although it will simultaneously increase our exposure to other fuels such as biomass, and on low carbon energy production technologies of which a part will continue to be imported. The relative costs of the low carbon scenarios compared to the reference scenario significantly depend on the assumptions made on fossil fuel prices: the Core scenario is assumed to have lower fuel costs (IEA 2DS) than the Reference scenario (IEA 6DS). With these assumptions the Core scenario has 50% lower fuel costs. With the same IEA 6DS assumptions on fuel costs it is only 38% lower (Figure 50).

In addition, the higher the fossil fuel prices, the more competitive the low carbon scenarios are compared to the reference scenario**.** So in a world with no action on Climate change, decarbonising is relatively more attractive than the reference case. Concretely, with oil prices at ~$70/barrel (IEA 2DS) it is 31% lower in fuel costs, and at ~$150/barrel, fuel costs are 38% lower.

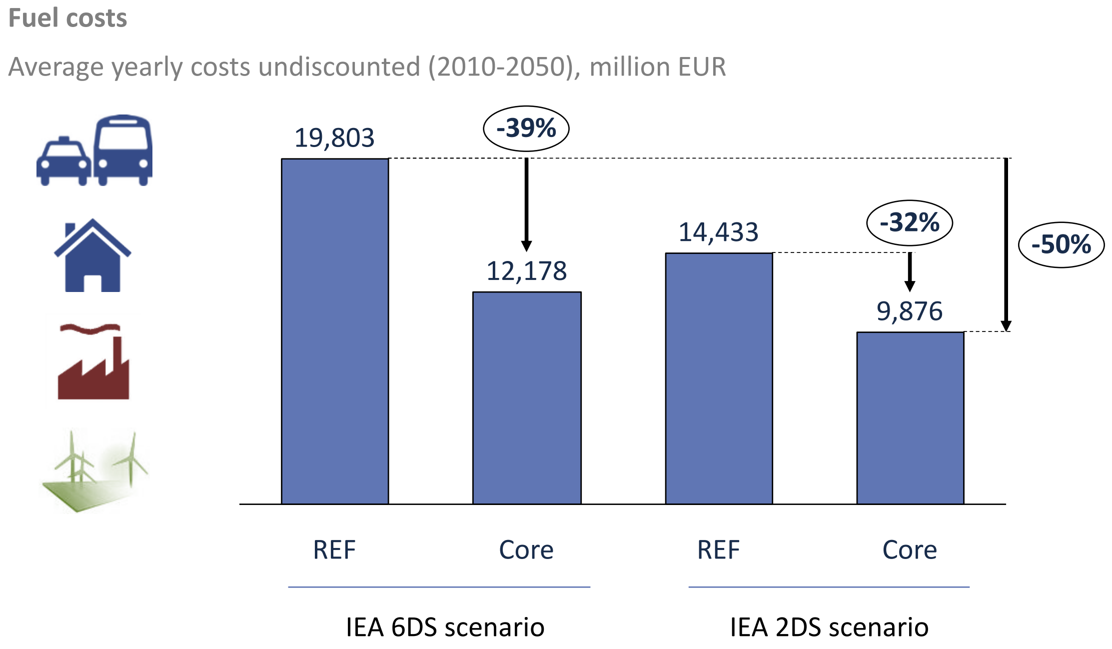

Figure 50. Sensitivity on fuel costs for the REF and Core scenario.

Sensitivity to discounting

As described in the methodology section, all system costs in this report are in real terms over time, without discounting them to 2010 (effectively applying a 0% discount rate), but it is clearly interesting to see the impact of such discounting on the cost differences.

Figure 51 shows the impact of applying a 10% discount rate on the yearly system costs over time (left-hand side) and on total costs over the full 40 year-period (right-hand side). When discounted with a higher rate, meaning that today's value of future cash flows decreases, a lower difference between the Core and REF scenarios is observed: investments in low carbon technologies are higher upfront (e.g., wind turbines, heat pumps, electric vehicles) and thus discounted less, while the larger fuel costs in the reference scenario appear in the later years scenario and are consequently discounted stronger.

This highlights one of the issues related to the implementation of the transition, namely the fact that financing the transition can be hindered in many sectors because returns on investment take place over long periods.

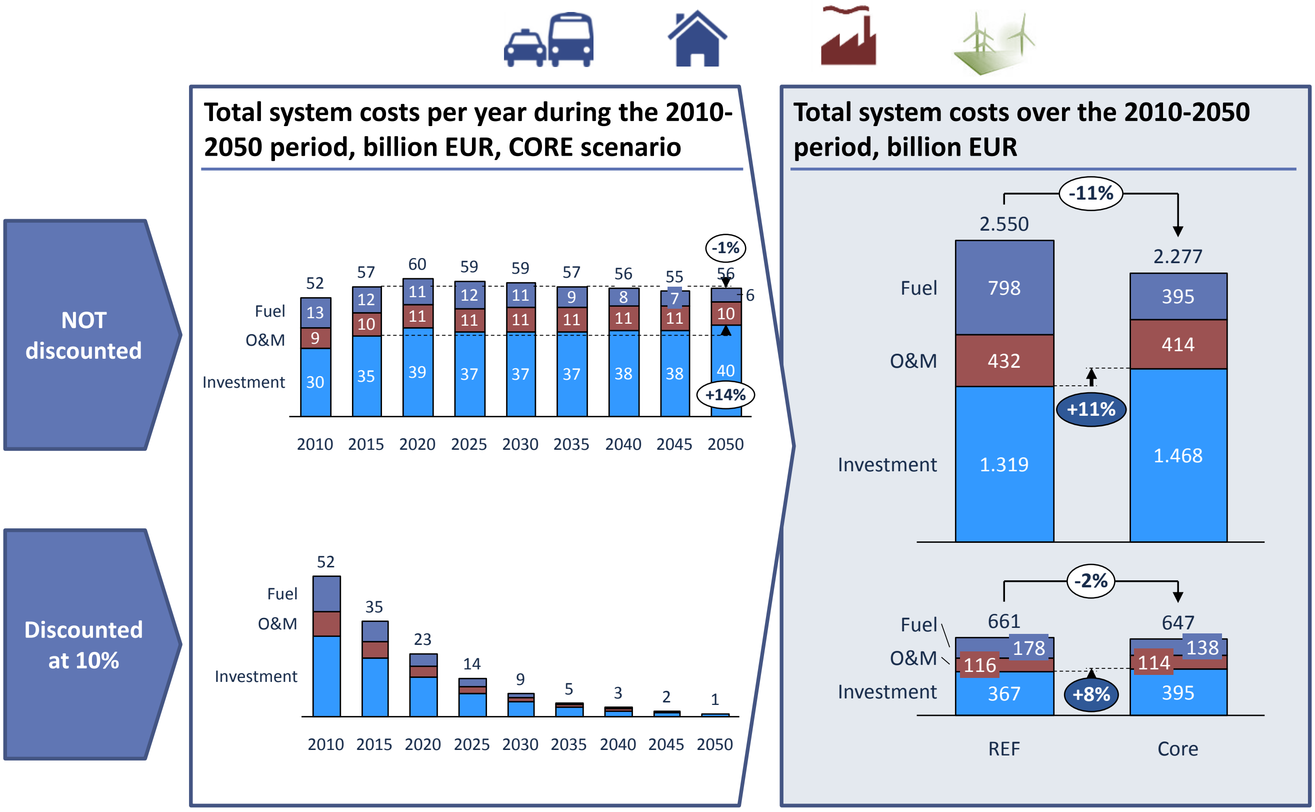

Figure 51. Impact of discounting on system costs.

Sensitivity to assumptions on population

Population is one of the main drivers for emissions in sectors like buildings and transport. Although many other societal issues, besides GHG emissions, are related to population size, it is still interesting to see the impact of population size on the different scenarios. Figure 52 illustrates the impact of shifting from the base case of the FPB assumptions on population (+16% from 2010 to 2050) to a higher increase (+31%). Reference scenario emissions are affected much more (from 14% to 9%) than emissions in the Core scenario (from -80% to -79%), as levers are simply applied on more houses or cars. On the costs side however, the impact is logically larger, and the 15% additional increase in population leads to 12% higher total system costs, hence a slight decrease in costs per capita.

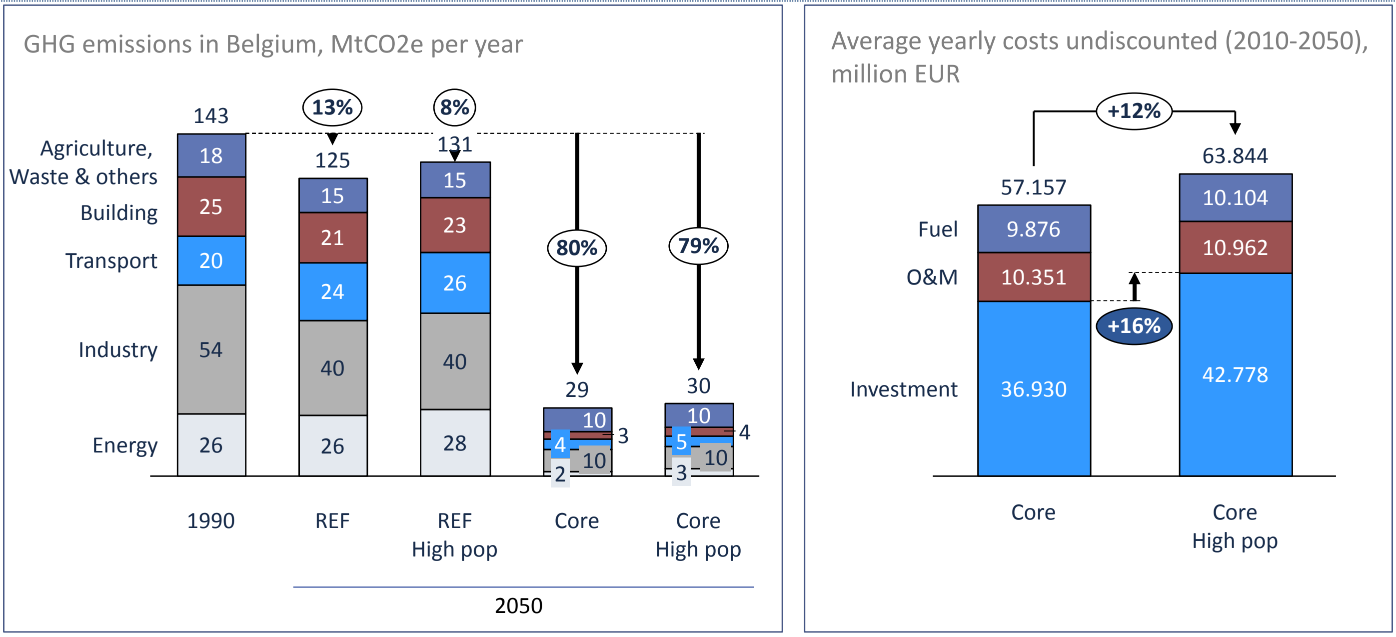

Figure 52. Sensitivity of GHG emission levels and scenario costs to population.

F.4 Milestones to 2050

While the OPEERA model is constructed to understand implications in the long term up to the year 2050, the model includes data, assumptions and results on fuel usage and emissions for intermediate years with a 5-year interval starting from 2010. This section explores how these intermediate years are constructed and elaborates on some of the key implications on GHG emissions trajectories, as well as on investment requirements over time.

Pace of implementation by sector

All sectors implement their levers at the relevant time and the relevant pace. For example, certain technological GHG abatement options in some industrial sectors are only expected to become available in 2025 or later (e.g. CCS is expected to become available from 2030 on). For most sectors and abatement technologies, the OPEERA model linearly interpolates the results between 2010 and 2050 as no other hypothesis seemed more relevant.

Overall, the following logic describes how each sector implements its levers over time:

Buildings

- Efficiency levels for renovations are mostly based on existing regulation levels from Europe.
- New buildings and renovations are assumed to happen gradually over time. More or fewer renovations take place according to the level of the renovation rate in each scenario.
- Heaters are also replaced gradually over time to reach a certain mix by 2050.

Transport

- Travel demand per person evolves over time based on the 2050 level defined by the user.
- Vehicle fleets are replaced gradually over time to reach a certain mix by 2050.
- Efficiency levels are assumed to reach levels set by regulation for 2020 and then to increase over time up to their 2050 potential.

Industry

- Product demand evolves gradually over time to reach the 2050 level defined by the user. In most industries however, industry specific refinements have been added at intermediary milestone, these typically address the expected addition of large plants in the short term or projection growths which differ before and after 2030.

- CO_2 intensity levers (energy efficiency, process improvements, fuel changes and CCS) are applied gradually from 2010 to reach the defined ambition in 2050. Here again in most industries, lever specific refinements have been added at intermediary milestones. These typically address the fact that easier actions can be applied before 2025 (such as the switch from fuel to gas), and less mature technology transitions are expected to be applied after 2025 (such as CCS, Oil & gas process improvements & Steel top gas recycling with Hisarna).

Agriculture

- The evolution in meat consumption from ruminants, and the related reduction in the amount of ruminant livestock primarily happens gradually over time.
- Most levers related to soil emissions are implemented gradually up to 2030, as their implementation is feasible in such a time frame.

Energy

- The planned evolution of nuclear capacity, with all plants being shut down by 2025, plays an important role in the deployment of technologies in the electricity sector and also in the profile of GHG emissions, as illustrated in Figure 53. Gas is used here as an intermediary solution which supports the transition. While technically it is easily feasible, it is unlikely that current market mechanisms would make the deployment of such gas plants profitable, as they would run at high capacity factors only a limited number of years. This transition period for the electricity sector thus requires much larger consideration.
- In sectors like solar and wind, which are relatively new and growing fast, the lifetime of the assets is shorter than for other power plants. Therefore, the replacement of the assets in the future play a major role. We assume a stable yearly deployment, which means that total installed capacities increase rather quickly and then mostly stabilize after 2030. This could support a more stable industrial environment.
- Enhanced Geothermal Systems to produce electricity are only assumed to pick up after 2025-2030 once these technologies have experienced further technology development and cost reductions.
- Biomass potential is assumed to be exploited in line with the 2020 identified potential by the experts in the various regions, and then to stabilize or only lightly gradually increase after that as further potential is uncertain. Imports on the other hand are assumed to increase gradually up to the user-defined 2050 levels.

Resulting GHG emissions trajectories

Although these milestones are not the result of any optimisation method, they give a good indication of near term challenges.

In the CORE scenario, the milestones in terms of GHG emission reductions with respect to 1990 are ~30% by 2020, ~45% by 2030 and ~60% by 2040 (see Figure 53).[73] Reductions take place at a relatively regular pace in all sectors with the exception of the energy sector in the years up to 2025 because of the gradual nuclear phase out. Reaching 95% reductions domestically by 2050 requires deeper reductions earlier on, namely ~40% by 2020, ~60% by 2030 and ~80% by 2040.

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[73] These milestones are relatively similar to those computed by the European Commission at the EU level in its "Roadmap towards a competitive low carbon economy in 2050".

GHG emissions in Belgium in the CORE scenario (index: 1990 = 100) and evolution per sector and in total w.r.t. 1990 (%)

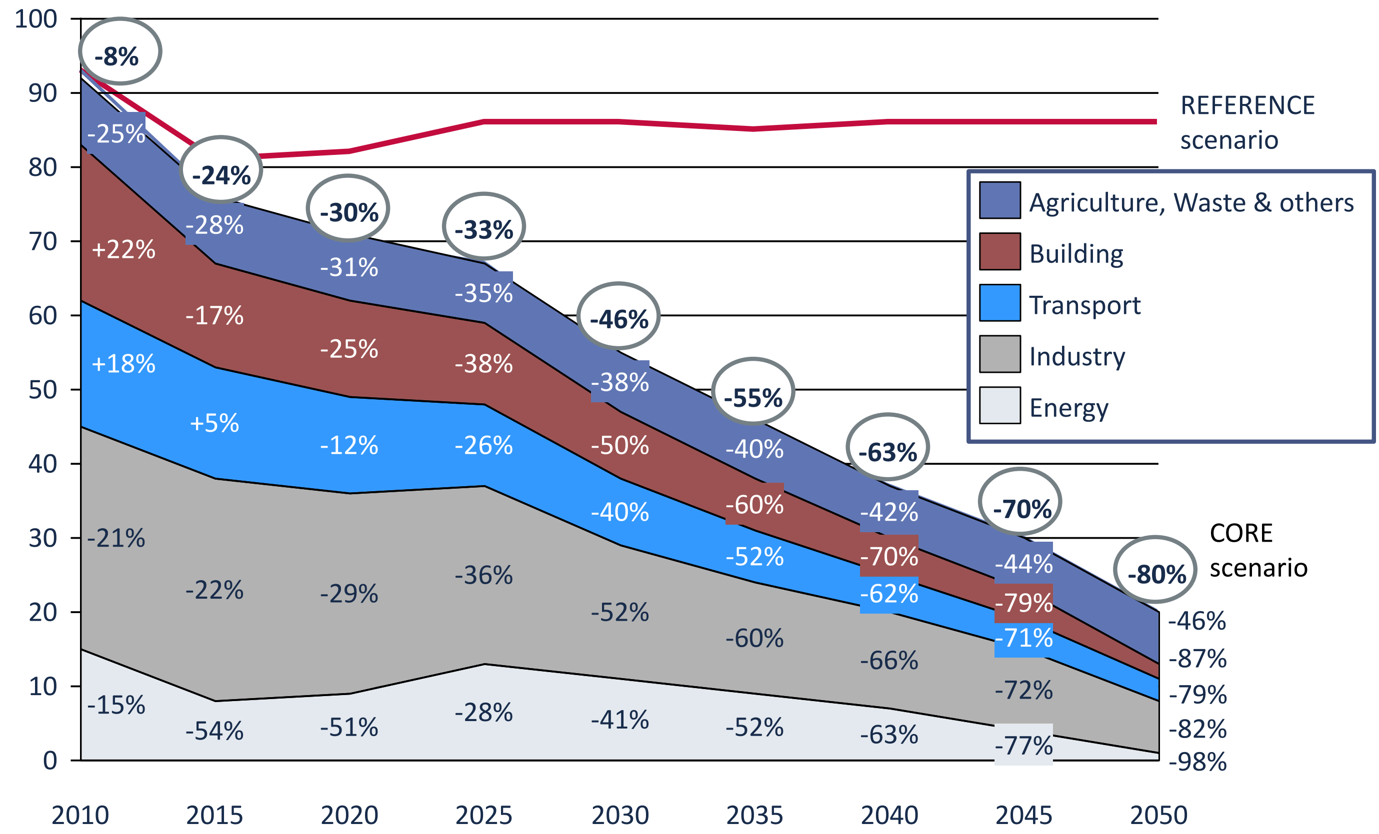


Figure 53: Evolution of GHG emissions per sector in Belgium in the CORE scenario.

In the BEHAVIOUR scenario, a more rapid GHG reduction effort can be observed leading to higher cumulative GHG reductions than in the CORE and the TECHNOLOGY scenarios, as illustrated in Table 11. The level 4 behaviour and lifestyle changes of this scenario can be implemented quickly and therefore lead to an immediate reduction. In the TECHNOLOGY scenario behavioural changes are only selected up to the level of the REFERENCE scenario. Because some of the technological options only become available in 2025 or later, this scenario follows a slower reduction path to reach the -80% in 2050. The difference between the 3 scenarios can be seen in the table below that also shows the additional reductions required in the -95% GHG and the EU INTEGRATION scenarios.

Alternative reduction pathways are potentially feasible, but lower reductions in the short/mid-term will lead to heavier efforts in future years, and may stretch the system beyond what is techno-economically feasible. The detailed descriptions of the levers in the detailed sector documents can help better understand the potential impact of such a delay (although no detailed analysis is made on the topic; this would deserve further work).

GHG reductions	1990	2010	2020	2030	2040	2050
CORE	0%	-8%	-30%	-46%	-63%	-80%
BEHAVIOUR	0%	-8%	-34%	-50%	-66%	-80%
TECHNOLOGY	0%	-8%	-28%	-44%	-62%	-80%
-95% GHG	0%	-8%	-38%	-59%	-78%	-95%
EU integration	0%	-8%	-35%	-53%	-71%	-87%

Table 11. GHG reduction over time for the low carbon scenarios.

Investment requirements over time

Investments, and the financing of these investments, are crucial for the transition. Figure 54 shows how these investments evolve over time for all scenarios. It is clear that larger GHG emissions reductions lead to a higher implementation of the levers, and to higher required upfront investments. However, the farther the behaviour and societal organization levers are pushed, the smaller the differences are from the reference case as some large investments are avoided, including parts of the car fleet or investment in larger new houses. This emerges particularly strongly when comparing the "-95% GHG" scenario and the "EU INTEGRATION" one. The latter does not implement the behaviour levers extensively (level 1), and leads to much higher costs with lower emission reductions.

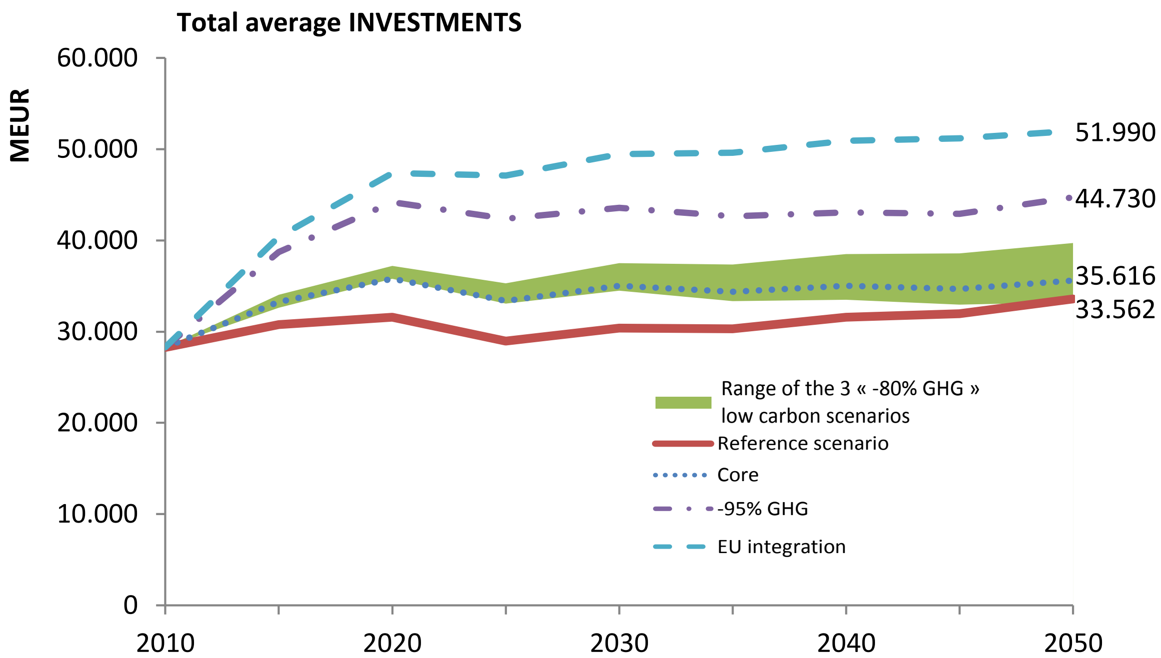


Figure 54. Evolution of the investment requirements over time across scenarios.

G. CONCLUSION AND NEXT STEPS

Attaining an 80 to 95 per cent GHG emissions reduction in Belgium is possible. Nevertheless, reaching this target is a heady challenge. It will imply large reductions in all sectors and a thorough understanding of the various interconnected dimensions is crucial.

This study analyses various scenarios to achieve significant GHG reduction objectives. The scenarios imply drastic changes from all actors in society. They request a clear political vision and a consistent framework allowing all stakeholders to engage in the low carbon transition while managing the many uncertainties of a 40-year time-horizon.

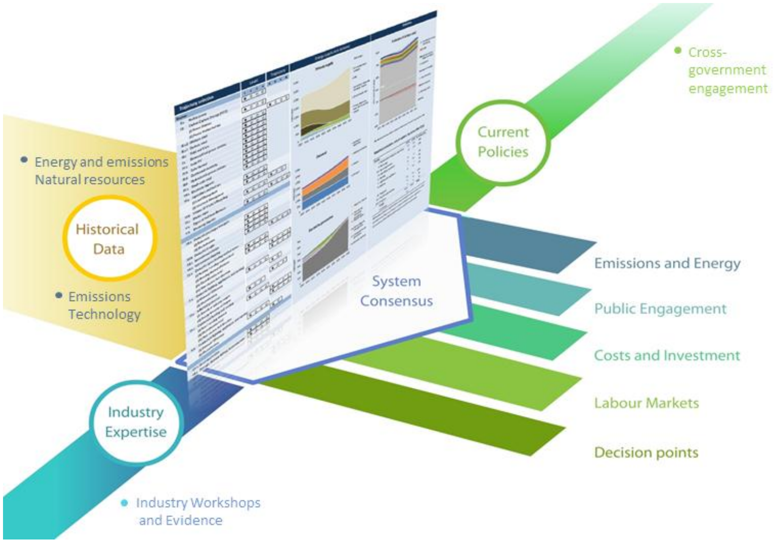
The study shows that, if managed correctly, the low carbon scenarios are situated in the same cost range as the reference scenario: large investments in energy efficiency, infrastructure, flexibility, renewable energy and interconnections are compensated by lower fuel expenses. It makes clear that energy savings in all sectors remain of central importance and that the transition can be made possible through early investments financed by later fossil fuel savings, placing the question of financing at the heart of the debate.

A low carbon transition offers opportunities and some ‘no regret measures’, such as renovating buildings, developing the energy infrastructure, or strengthening energy efficiency. However, critical barriers could make the transition difficult and thus moving to a low carbon society must come about in a coordinated way, in order to properly manage competitiveness issues, ensure security of supply and provide the necessary conditions for a just transition. The directions taken by other regions and countries need to be taken into account as their decisions will affect the availability of resources, prices and technology development and therefore will have an influence on the context in which a Belgian low carbon transition will take place.

This study aims to provide stepping stones to initiate a profound societal debate on orienting our economy and society towards a low carbon development, while identifying common ground, no regret measures and essential milestones. The different scenarios intend to identify and outline the changes required and their main implications, and provide some answers. They also illustrate the need for further work on complementary topics such as macro-economic implications, employment and training, competitiveness, financing, co-benefits, etc. This complementary work will be important in identifying which pathway to 2050 is most desirable and deliverable.

H. APPENDIX

Appendix 1 – OPEERA model



OPEERA is a Microsoft Excel tool developed in 2010 by the Department of Energy and Climate Change (DECC) in the UK with experts from businesses, NGOs, technical fields and academics for the simulation of energy demand and supply scenarios towards 2050. The tool can be used to build, validate and compare prospective energy demand and supply scenarios on the long run for a defined geography. It also computes and reports on specific impacts of scenarios on climate change (GHG emissions), costs (investments, operating and fuel costs) and land use. It is a back-casting tool: it does not optimize for the best alternative solution but rather assesses the impacts of a predefined long term objective and the chosen way to reach it.

It can be used as a decision tool for policies and infrastructure development since it can simulate and compare several scenarios with a 'business-as-usual' scenario or legal compliant targets for energy consumption and GHG emissions level.

OPEERA is an Open-Source tool based on Microsoft Excel. It does not use any programming language (no macro) and therefore only requires relatively basic MS Excel skills. Interface and architecture are very user friendly and make the files easy to work on and share as a team. The tool is a (~13MB) template file that can run on any PC and can be sent by email and be replicated to model several regions. It can also be linked with other Excel workbook to create consolidation reports and charts.

The OPEERA tool is very flexible and can be entirely adapted to fit with geographic or technical specific needs. Each energy demand and supply sector is modelled in separated tabs that can be bypassed or duplicated to provide greater or less granularity on technologies. It can apply to any geographical level from local collectivity, region, country or multi-country environment.

Audience and users

The Excel based OPEERA tool can be used by a broad variety of users as simulation and decision tool for energy and GHG emissions: Country or regional decision makers, academics, consultants, industry representatives, NGOs, etc.

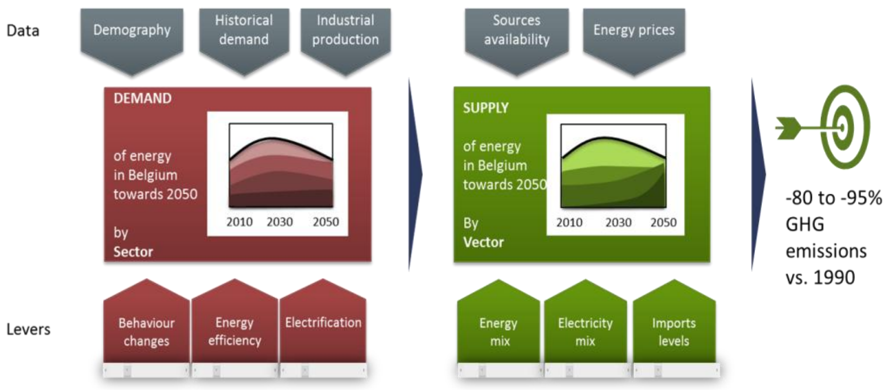
OPEERA can also be transposed easily into an online web tool for wide public consultation. DECC (UK) developed the online version of the '2050 calculation' available at http://2050-calculator-tool.decc.gov.uk

Other online versions of OPEERA have been developed by China and the Walloon region.

Model characteristics

OPEERA is based on a bottom-up equilibrium between energy demand and energy supply to calculate energy mix, GHG emissions levels and costs for each scenario.

A scenario is defined by the combination of effort levels for a (flexible) set of drivers related to sectors. Those drivers are often described as either 'trajectories' on which authorities have little or no influence (as demographic trends, industry production trends, evolution of energy prices) or 'levers' which can be directly influenced. Both of these can be switched by the user to model overall trends and several levels of reduction efforts (behaviour changes, efficiency electrification, energy mix, imports levels).



Total energy demand for a specific scenario will be derived from the choices made by the user on these trajectories and levers for transport (people and goods), buildings (residential and tertiary) and industries (split by sectors incl. agriculture) in the 'control panel'. Effort levels for each drivers range from [1] 'Business-as-usual' or minimum legal requirements to [4] maximum technical potential. One can thus choose to do the minimum legal within one sector and focus all efforts [4] on another sector to reach energy and GHG emissions target.

Energy supply will then be calculated to answer the simulated energy demand and the mix defined by the drivers (all renewable technologies, biomass, nuclear, fossil fuels…). Import/export of energy is also taken into account. The tool also calculates the impact on electricity transmission and distribution networks, backup power plants and storage to balance intermittency. Carbon Capture and Storage is included as one of the options and the model derives the requirements in terms of carbon transport.

Key outputs of the OPEERA tool are (in tables and charts format – can be easily customized for specific purposes)

- Primary and final energy demand levels by sectors and energy vectors
- Electricity and heat demand by sector and production by source
- GHG emissions by sector and by IPCC sources
- Cash flows (investments, fuel costs and operating costs) by sector
- Energy flows
- Energy security
- Land surface usage

References

The tool has been used in the UK, Walloon region in Belgium, China, and Bangladesh. A set of other countries are in the final stages of setting up projects to build their own tools (India, Brazil, South Africa, etc.)

More information

http://www.decc.gov.uk/en/content/cms/tackling/2050/2050.aspx

http://www.wbc2050.be/ (in French)

http://2050pathway-en.chinaenergyoutlook.org

Appendix 2 – Description of the alternative scenarios

A.2.1. « BEHAVIOUR » scenario

Description

The "BEHAVIOUR" scenario achieves a 80% GHG emission reduction. It elaborates on the implications of a transition with a significant focus on behaviour, lifestyle changes and societal organisation changes such as lower transport demand, less meat consumption, and a lower level of heating and cooling in houses. The levers related to such changes are set at their 4th level of ambition. This leads to a lower growth trajectory in the food sector as significant efforts are realized on dietary changes while other sectors experience middle growth industry trajectories. At the same time, a generalized lower fuel demand reduces the need for refined products, leading to a lower trajectory in the refinery sector. All this reduces the reliance on technological levers with respect to the CORE scenario. It is important to underline that these lifestyle changes lead to different ways of living that can have both positive and negative aspects (e.g., lower transport can be due to lower travel distances to work, and lead to fewer traffic jams). Further lifestyle changes are possible beyond level 4, this as has been repeatedly indicated by some stakeholders, e.g. in the further reduction of individual transport or in heating and cooling appliances.

Context and demography

The population grows in the same way as in the REF and the CORE scenario (+16% by 2050). Energy prices reflect the prices of the 2 degrees scenario of the IEA to reflect a global climate change deal.

As in the Core scenario, energy prices reflect the prices of the 2 degrees scenario of the IEA to reflect a global climate change deal.

Transport

The transport demand per person drops by 20%, with less than 9,000 km/passenger/year in 2050 vs. over 11,000 km/passenger/year in 2010. The modal split evolves: people use their cars less (from 77% to 55% of the passengers-km), home-working is developed, carpooling increases together with the occupation level and the shares of public transport and walking and cycling increase accordingly, thanks to improved infrastructure and higher service levels in public transport. There is a significant shift in the way people consider driving a car, and policies reward working close to home.

Those evolutions make it possible to require a lower ambition level for energy efficiency for passenger transport: 55% of cars are plug-in hybrids (30% of buses) and 10% battery electric by 2050 (20% of buses), ICE vehicle fleet is ~40% more efficient than current fleet, plug-in hybrids are 40-45% more efficient and electric cars are ~45% more efficient; ICE, hybrid and electric buses are ~20% more efficient. Rail transport's efficiency is ~20% more efficient.

The increase in freight transport is low and there is a shift from lorries to train and boats.

Buildings

The current trend of increased urbanization is extended, with a 1.2% increase in the share of multi-family buildings in the total of new houses per year up to 77% in 2030. After 2030 the share of multi-family buildings remains at the level typically reached in urban areas nowadays.

The average internal temperature drops to 16°C, which is a combination of an internal temperature of 18°C to 20°C in the living rooms and 14°C in the bedrooms.

New constructions are well insulated and use efficient heating and natural cooling systems; they only require 15 kWh/m² as from 2020 (final energy consumption) and a large share uses a combination of heat pumps and thermal solar panels. In 2050, 85% of the installed heating installations in the residential buildings are heat pumps.

Through appropriate supporting schemes almost all houses can be renovated by 2050 except some of the historical buildings (average renovation rate between 2010-2050 of about 2.5% compared to 1% historical renovation rate).

Lighting and appliances are very energy efficient and require up to 40% less energy than in 1990 through the use of LEDs, improved electronics and appliances and more careful use of lighting and appliances.

The evolution in office buildings is similar.

Industries

The parameters related to technological changes are set at a lower ambition level. There is no massive technological development on the demand side.

Due to lower demand, CCS is not necessary in the BEHAVIOUR scenario, although this requires other sectors to stretch their ambition level even further.

Agriculture (non- CO_2)

Diet changes lead to a strong decrease in meat consumption, and a resulting decrease in the number of animals by 43% in 2050 compared to 2010. This leads to ~24 mio animals in 2050. Various reduction measures such as nutritional management and optimizing ration per animal lead to a reduction in the emissions per animal. The increase of production efficiency reduces the number of animals required to produce the same amount of meat. Along with that, a larger share of manure is treated in anaerobic digesters and good manure management practices increase. All this leads to a reduction in the emissions per animal of 3.1% per year up to 2030, and a stabilization after that to 2050. There are no specific changes in the European common agricultural policy.

Improvements in the use and the efficiency of nitrogen reduce the amount of N input to the soil and reduce direct emissions. Additionally, the decrease in the nitrogen excreted also reduces emissions from grazing.

This leads to a reduction in the overall emissions on agricultural soils of ~0.7% per year up to 2030, and a stabilization thereafter up to 2050.

All GHG emissions from waste management are linearly decreased and reach zero carbon in 2050.

Energy supply

With respect to the CORE scenario, behavioural changes reduce the energy demand further and, thereby, total electricity production requirements.

The BEH scenario leads to a decrease in final energy demand from ~435 TWh to just above 200 TWh (Figure 55). Bioenergy imports are also similar.

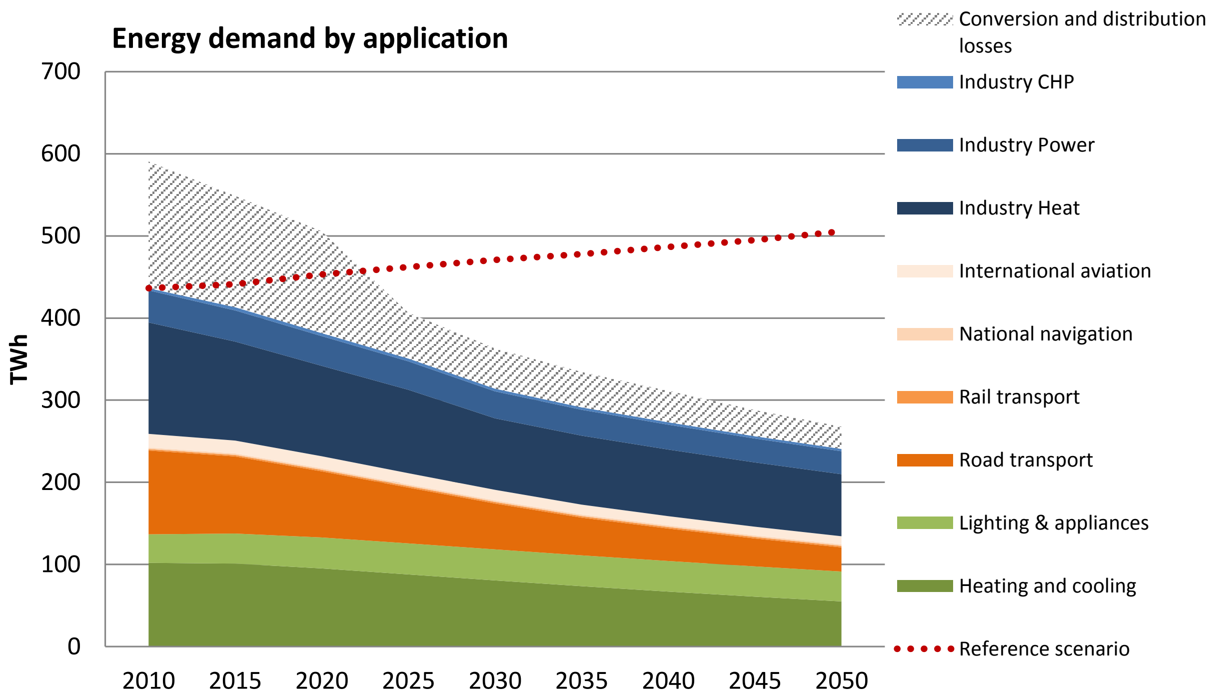


Figure 55. BEHAVIOUR, Energy demand.

As regards electricity production (Figure 56): nuclear electricity production disappears completely by 2025 and is replaced by more gas production and RES production. As from 2025, gas decreases as RES production from wind, solar, biomass, geothermal and CHP see their role increasing. Intermittent RES represents ~45% of the mix in 2050. A capacity of 6.6 GW for onshore wind, 4.9 GW for offshore wind and 11.2 GW for solar PV is achieved in 2050 (vs. respectively 8.0 GW, 7.0 GW and 21.0 GW in the CORE scenario). The maximum level of electricity imports, needed when production is not sufficient, is reduced to 2.5% (vs. 5% in the CORE scenario).

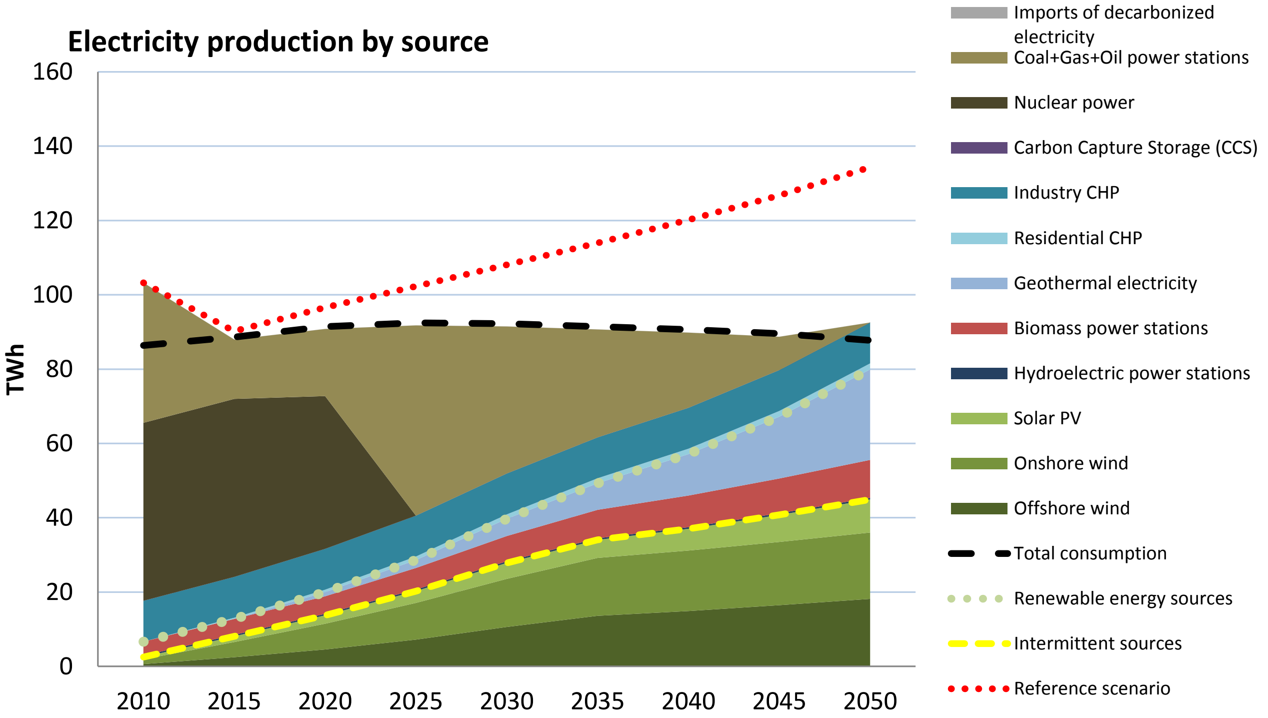


Figure 56. BEHAVIOUR, Electricity production by source.

GHG emissions

Figure 57 illustrates the GHG emissions in the BEHAVIOUR scenario, reaching 80% reduction in 2050 over 1990. Industry remains the most GHG emitting sector with 18 $MtCO_2e$ of the 29 $MtCO_2e$ remaining in 2050 while Transport, Buildings and Energy decrease massively. Buildings are zero carbon and Energy is almost zero carbon.

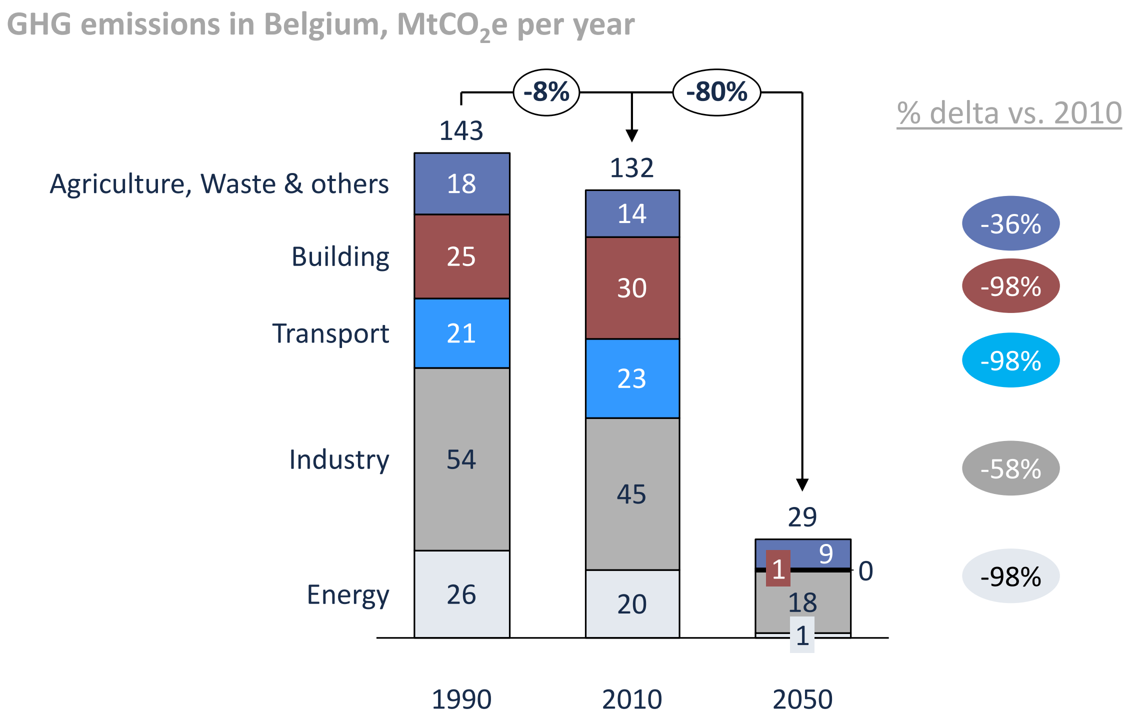


Figure 57. BEHAVIOUR, GHG emissions, sectoral view.

A.2.2. « TECHNOLOGY » scenario

Description

The “TECHNOLOGY” scenario achieves 80% GHG emission reduction. It elaborates on the implications of a transition mainly driven by technological evolutions. Behavioural changes evolve only incrementally compared to the REF scenario. With lower changes on the behaviour side, it is necessary to increase the use of technological abatement options to achieve the reduction levels. Energy demand is higher and requires higher deployment of supply technologies, including CCS in the power sector.

Context and demography

The population grows at the same rate as in the REF and the CORE scenario (+16% by 2050). Energy prices reflect the prices of the 2 degrees scenario of the IEA to reflect a global climate change deal.

Transport

The transport demand per person increases by 8%, with about 12,000 km/passenger/year in 2050 vs. 11,000 km/passenger/year in 2010. The modal split and the occupation rates increase slightly.

A strong improvement in the efficiency of internal combustion engines, on the order of ~50%, is coupled with a ~30% to 40% efficiency improvement of buses and trains and the deployment of new technologies such as EV, PHEV, and fuel cells. Transport is highly electrified.

There is a large increase, of ~45%, in freight transport and the share of lorries stays stable at 70% of the km travelled.

Buildings

The share of flats in new housing stock is kept constant at current level until 2050, namely 53%.

Average internal temperature in households rises to 19°C by 2050, the hot water demand per household increases by 60% in 2050 compared to current hot water demand, cooling reaches 40% of the households by 2050 compared to 4% today.

New constructions are well insulated and use efficient heating and natural cooling systems; they require 30 kWh/m² as from 2020 (final energy consumption) and use a combination of heat pumps and thermal solar panels. In 2050, 85% of the installed heating installations in the residential buildings will be heat pumps.

In 2050, 60% of all houses are renovated as the rate of renovation increases to 1.5% per year between 2020 and 2050.

Innovative technologies (district heating with CHP/cogeneration or heat from power stations, micro-CHP, and geothermal energy) represent 40% of the non-electric heating installations.

Industries

Various GHG abatement curves are strengthened. Energy efficiency for instance evolves quickly in the various industrial sectors, positioning Belgium at the top of the EU in the GHG/unit of output.

Sector	Production (2050 vs. 2010)	Energy and Carbon intensity per output (2050 vs. 2010)
Steel	Stabilized production	• Increase of electro-steel by 17% by 2050 vs. 2010 (shifting Wallonia integrated steel production to electric), • +25% shift to high processability steel, • 5% improvement of overall energy efficiency in integrated steel

		production, • Introduction of Hisarna technology
Cement	Growth of +0.23% per year (+10% by 2050), supported by the building sector	• Clinker substitution by steel slag reduces energy and process emissions by -53% by 2050 vs. 2010, • Energy efficiency increases by +34%, • Fuels are substituted at 66% by solid biomass
Lime	Stabilized production	• Energy efficiency increases by +30%, • Lignite is substituted at 66% by gas, • Fossil fuels are substituted at 20% by solid biomass
Glass	Growth of +1.7% per year (doubling by 2050), with hollow glass remaining stable	• Energy efficiency increases by +30%, • Cullet use increases by +10%, • Oxyfuel use increases efficiency by +24%, • Fuel is substituted at 100% by gas in 2030, • Fuels are substituted at 6% by solid biomass.
Chemicals	Stabilization of the ETS sectors; increase of 20% of the non-ETS	• Penetration of 20% green chemistry, replacing traditional plastics, • 20 to 30% energy efficiency gains, • 90% reduction of N2O emission
Pulp & paper	Stabilized production	• Energy efficiency increases by +20%, • All liquid fuels substituted by gas, • Solid fuels substituted at 85% by biomass in Kraft pulp mill
Oil & gas refineries	Correlated to fuel demand in the transport and buildings sector	• Energy efficiency increases by +30%, • 15% extra implementation of CHP, • Fuel substituted at 50% by natural gas, • Process improvement applied starting from 2030, 15% reduction energy use
Food & Drinks	Correlated to agriculture production	• Energy efficiency increased by +30%, • All solid and liquid fuels switched to gas, • Gas substituted at 50% by biogas
Non-ferrous metals	Stabilized production	• Energy efficiency increases by +20%, • All liquid fuels substituted by gas, • Gas substituted at 50% by biogas
Ceramic	Growth of +3.5% per year between 2015-2025; stable after 2025 (+68% by 2050 production). Production driven by demand for bricks for new buildings	• Energy efficiency increases by +30%, • All solid & liquid fuels substituted by gas, • Gas substituted at 50% by biogas
New technologies to abate GHG emissions, e. g. CCS	All the installations producing above 300KtCO_2e /year are equipped with CCS and their residual emissions are reduced by 85%	

Agriculture (non- CO_2) and waste

The TECHNOLOGY scenario assumes, with an increasing population and slightly evolving diets, that meat consumption decreases slightly and results in a 16% decrease of the number of animals in 2050 compared to 2010; this leads to ~35 mio animals in Belgium in 2050.

Emissions of manure per animal increase by ~1.1% per year from 2010 to 2030, followed by a stabilization of the emissions per animal up to 2050 due to an increase in productivity.

Energy supply

The TECHNOLOGY scenario assumptions lead to a decrease in final energy demand from ~435 TWh to almost 320 TWh (Figure 58).

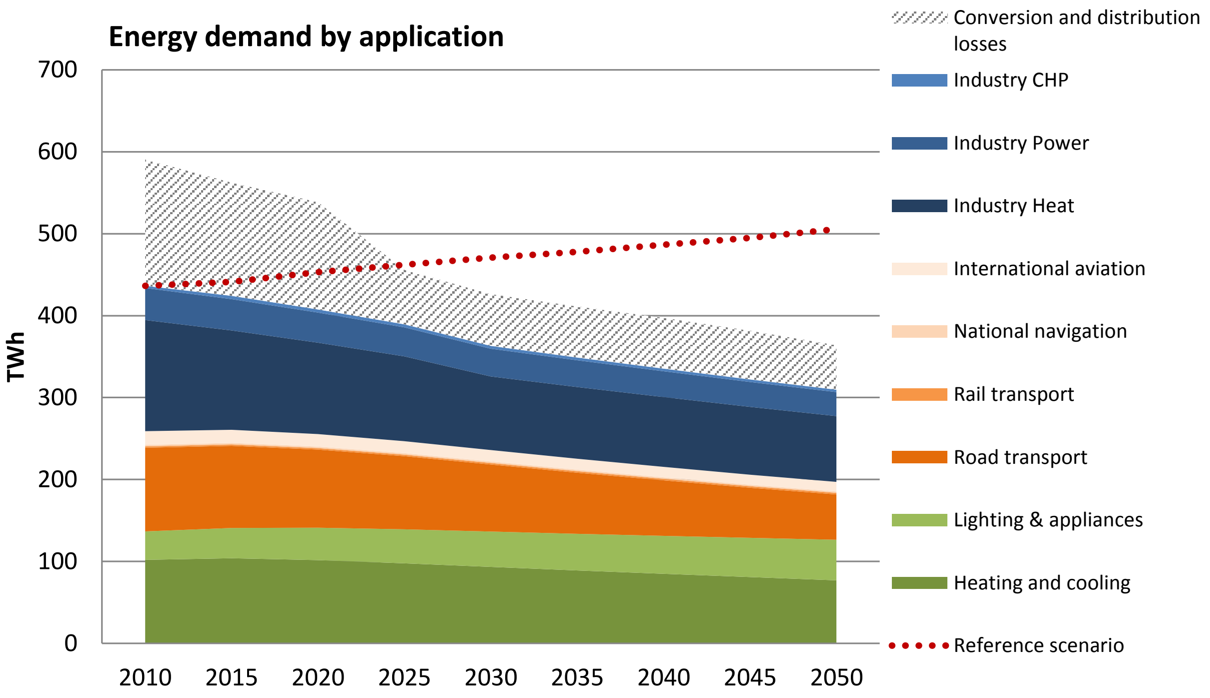


Figure 58. TECHNOLOGY, Energy demand.

In the TECHNOLOGY scenario, electricity generation relies a little more on enhanced geothermal energy, the capacity of which increases gradually to 430 MW in 2025, rapidly ramping up to reach 4.9 GW of installed capacity in 2050. Moreover, CCS is used in electricity production: 2.3 GW of CCS capacity is built after 2030. This would cover ~10% of current electricity demand. This leads to lower intermittency levels.

All other electricity generation levers are set at a level similar to the CORE scenario. Bioenergy imports levels are also in the same range.

Figure 59 represents the sources of electricity production in the TECHNOLOGY scenario.

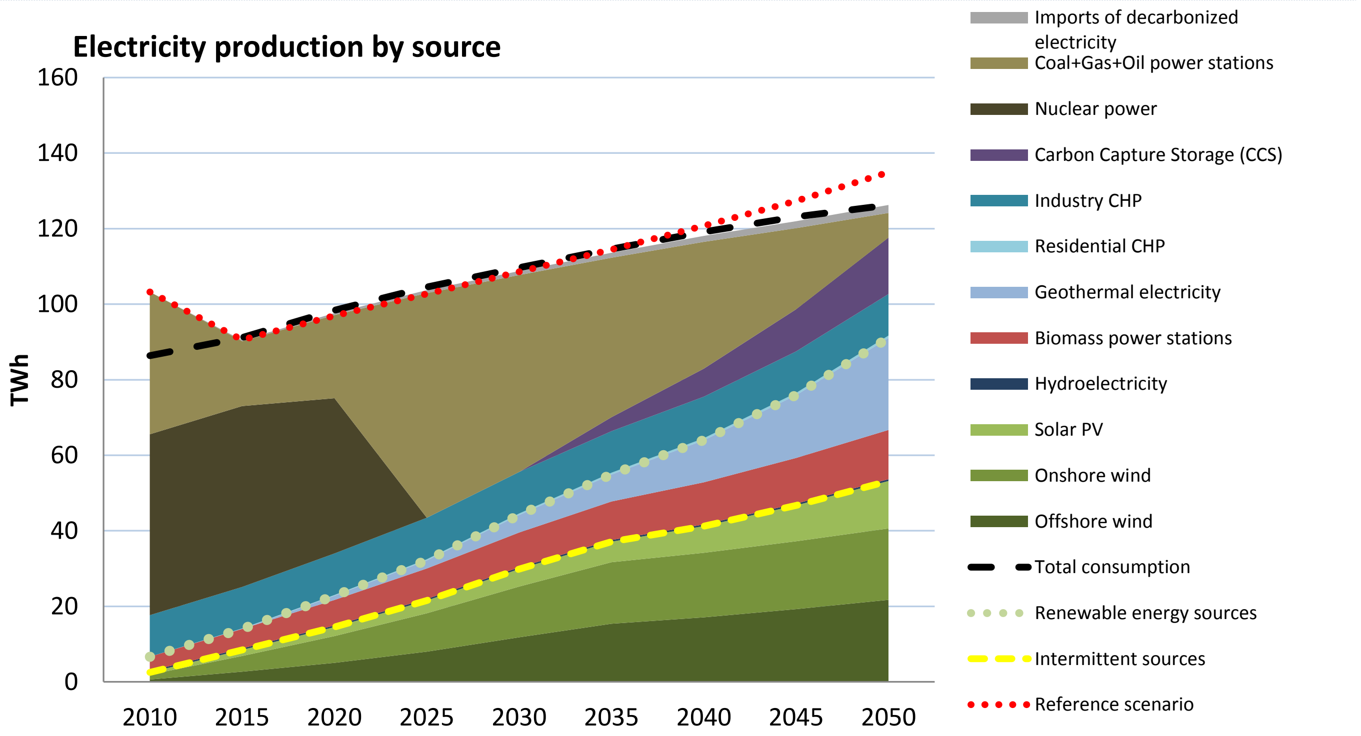


Figure 59. TECHNOLOGY, Electricity production.

GHG emissions

Figure 60 illustrates the GHG emissions in the TECHNOLOGY scenario, reaching 80% reduction in 2050 vs. 1990. Agriculture represents the most GHG emitting sector with 11 $MtCO_2e$ of the 28 $MtCO_2e$ remaining in 2050 while Transport, Buildings, Industry and Energy all decrease significantly. Buildings are almost zero carbon.

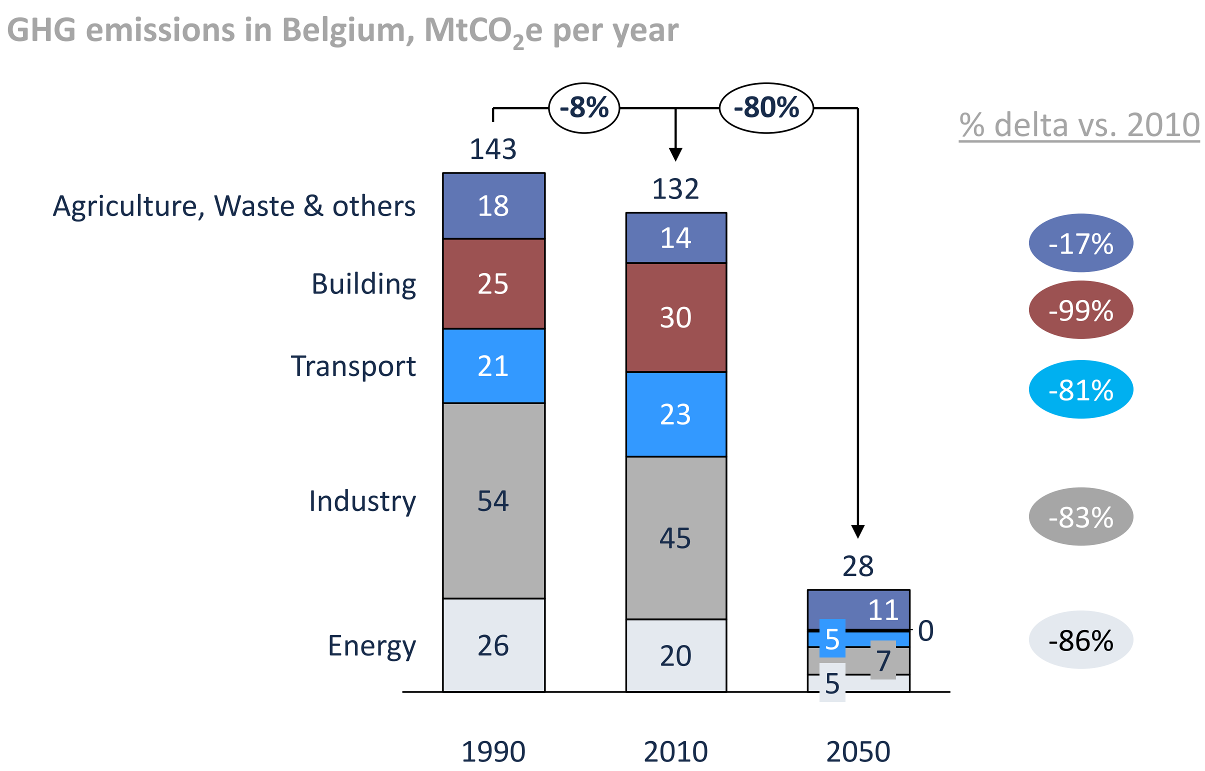


Figure 60. TECHNOLOGY, GHG Emissions, sectoral view.

A.2.3. The "-95% GHG" SCENARIO

Description

This scenario reflects the highest ambition in the GHG emission reduction target range modelled in this study. It represents a major challenge for society, but not necessarily a complete paradigm shift.

It implies significant efforts from all stakeholders and all actors in the society as lifestyles changes need to be combined with heavy technical GHG reductions including CCS.

All demand-side levers are set at their technical potential (level 4). According to some stakeholders, further lifestyle changes are possible beyond level 4, resulting in yet higher ambition levels, such as in transport (e.g. reducing personal transport further), in buildings (e.g. new housing solutions, adequate insulation and proper temperature management) or in consumption patterns (e.g. eating less meat). These would enable further GHG reduction and release a significant part of the technical effort. These lifestyle changes do not occur overnight and they require significant investments, through means such as awareness campaigns and communication.

GHG emissions

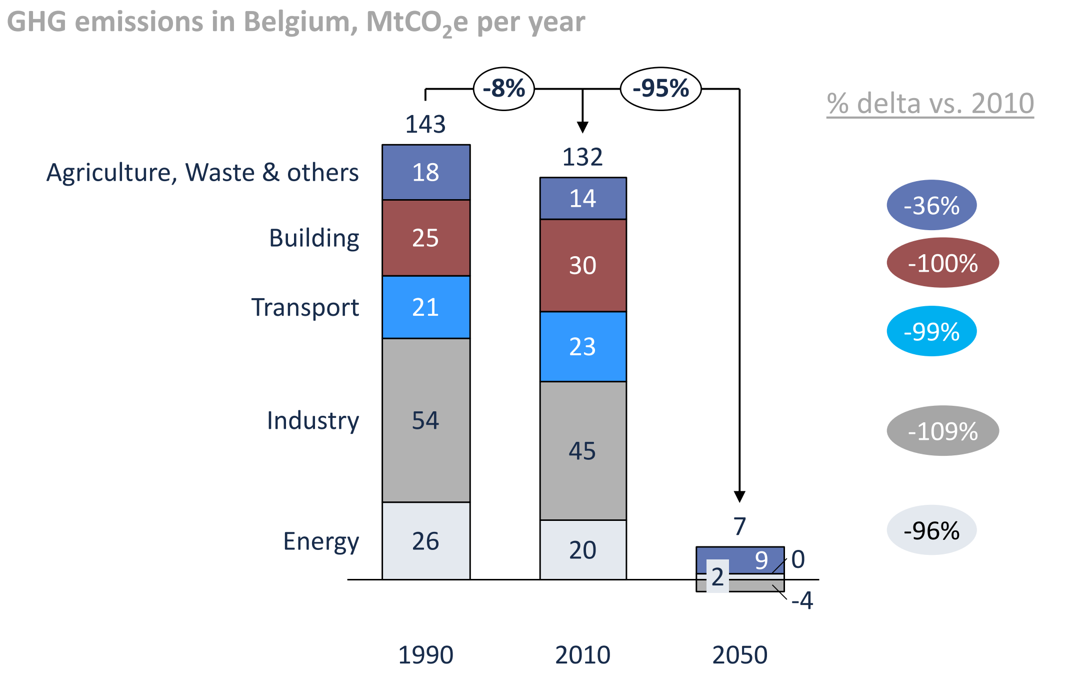


Figure 61. -95% GHG, GHG emissions, sectoral view.

In the "-95%" scenario, emissions are drastically reduced, up to 100%, in all sectors except agriculture. This confirms the findings of the EU low carbon economy roadmap that it is particularly challenging to reach very high emission reductions in this sector. Although important changes in meat consumption behaviour help to reduce the emissions by over 2 $MtCO_2e$, we are left with about 9 $MtCO_2e$ in 2050 in the agriculture sector.

One element that has not been exploited in the model is the level of exports in Agriculture, a sector particularly export-orientated as it currently represents ~ 5.7% of total Belgian exports. In particular, the degree of self-supply of meat production is currently around 170%. Reducing this level to 100% in 2050 would allow Belgium to reduce its emissions by a further ~1.0 $MtCO_2e$, leading to a total emissions of 5.3 $MtCO_2e$ in the agriculture sector. This reduction will of course affect the sector and will impact the trade balance.

Energy system

The "-95%" scenario assumptions lead to a decrease in final energy demand from ~435 TWh to almost 205 TWh, significantly below the CORE scenario at 270 TWh (Figure 58).

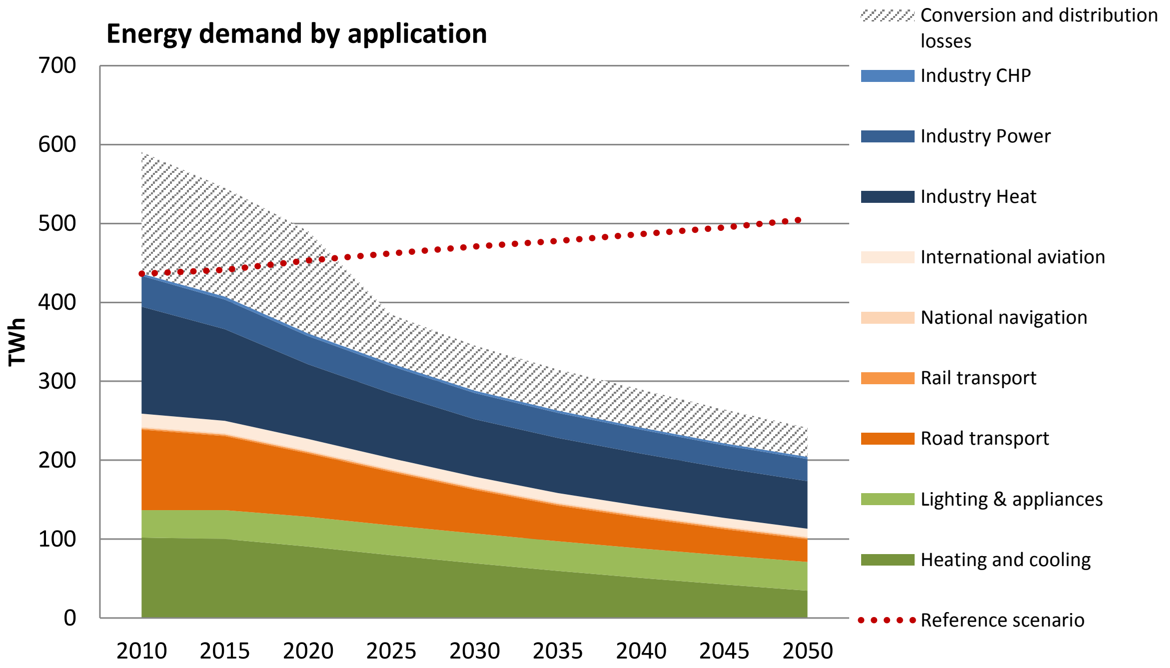


Figure 62.-95% GHG, Energy demand.

With demand levers all set at level ambition 4, electricity demand is logically low. However, it is higher than in the behaviour scenario, as the electrification levers are also pushed to the maximum. Figure 59 represents the sources of electricity production in the -95% GHG scenario.

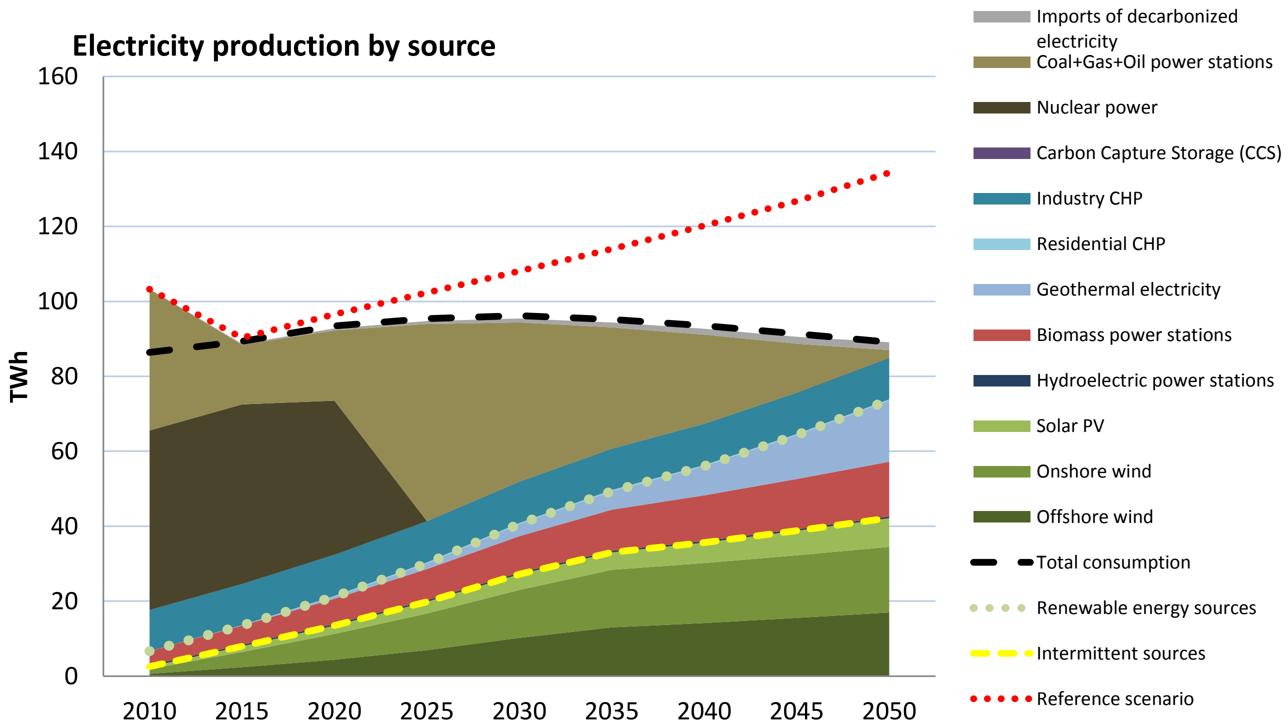


Figure 63. -95% GHG, Electricity production by source.

A.2.4. « EU INTEGRATION» SCENARIO

Description

The purpose is to build a scenario characterised by an energy system based mainly on renewable energy sources and on little fossil fuel energy. The aim is also to illustrate the implication of a decarbonisation scenario relying heavily on intermittency sources and to derive messages on, amongst others, transmission and back-up requirements. Such a scenario will be based on the assumption that European electricity grids are strongly developed and that European energy markets are highly integrated. We refer to section "Grids: managing intermittent electricity production sources" and "F.1 Implied trajectories on key variables" for more details on the grid and back-up discussion.

The pure behaviour levers are set at ambition level 1, as in the REF scenario. At the same time, the efficiency and electrification levers are set to ambition level 4. These assumptions lead to the highest electricity demand.

GHG emission reductions are somewhat larger than in the CORE scenario, with a GHG reduction of ~88% through a higher electrification level and a slightly higher development of all renewable energy sources. Still, the full potential of those sources would not need to be exploited.

Energy supply

The EU INTEGRATION scenario assumptions lead to a decrease in final energy demand from ~435 TWh to almost 265 TWh (Figure 58).

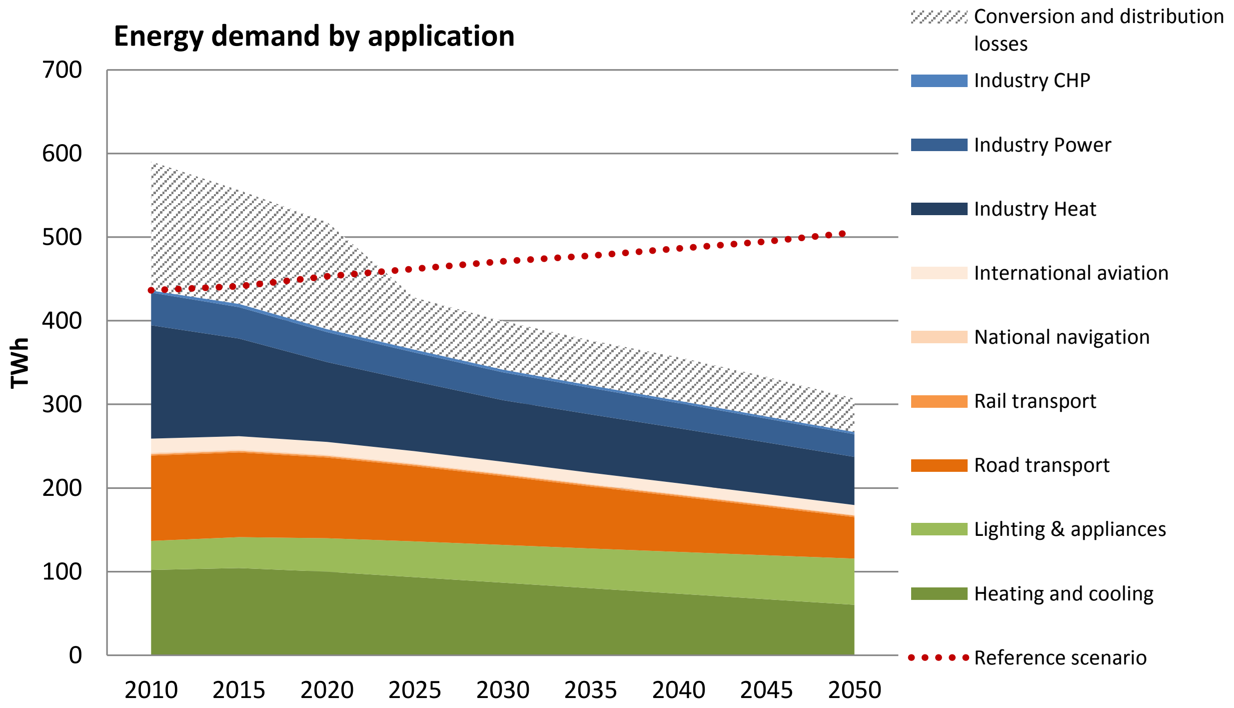


Figure 64. EU INTEGRATION, Energy demand.

In terms of electricity production, intermittent sources are exploited extensively, leading to a large share of intermittent generation of ~60%, which requires large grid and back-up deployment. It is effectively a 100% RES production mix if one excludes the CHP which will partly use natural gas.

Figure 59 represents the sources of electricity production in the EU INTEGRATION scenario.

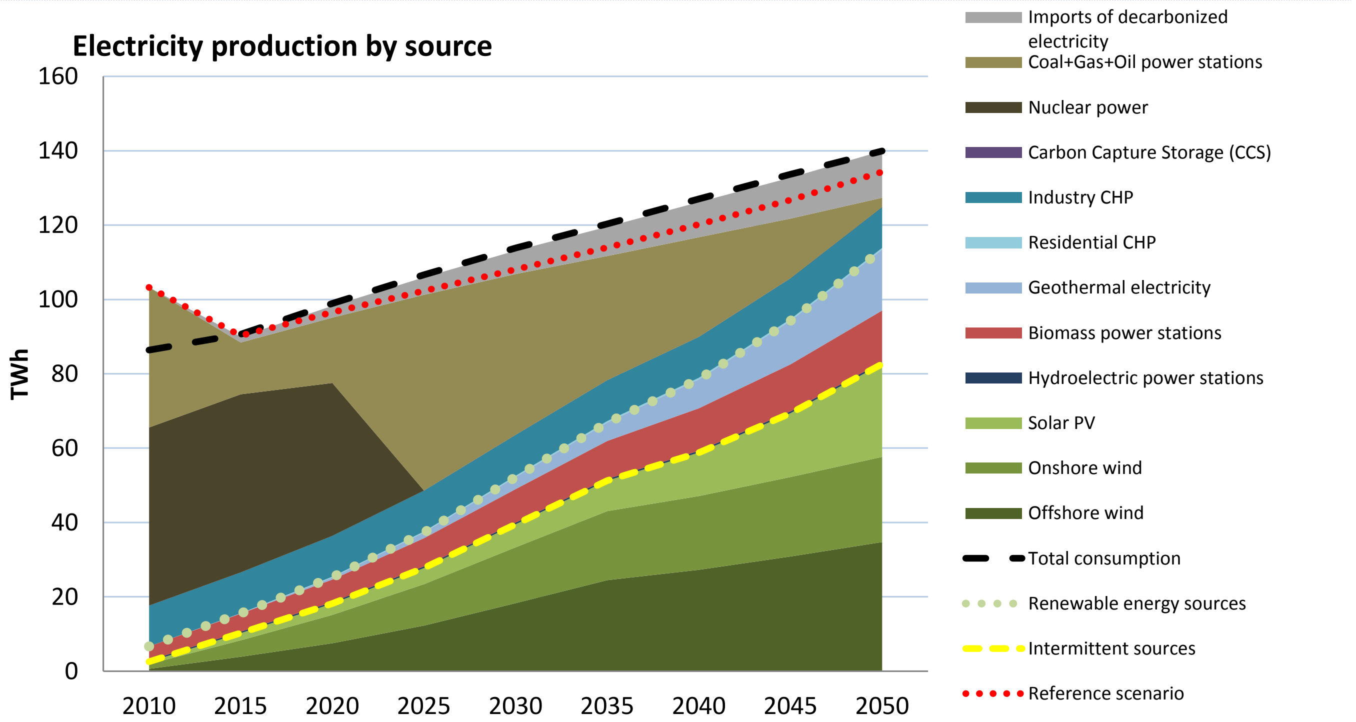


Figure 65. EU integration, Electricity production.

GHG emissions

Figure 66 illustrates the GHG emissions in the EU INTEGRATION scenario, reaching 88% reduction in 2050 over 1990. Agriculture represents the highest GHG emitting sector with 9 $MtCO_2e$ of the 18 $MtCO_2e$ remaining in 2050 while Transport, Buildings, Industry and Energy all decrease significantly. Buildings, Transport and Energy are effectively zero carbon.

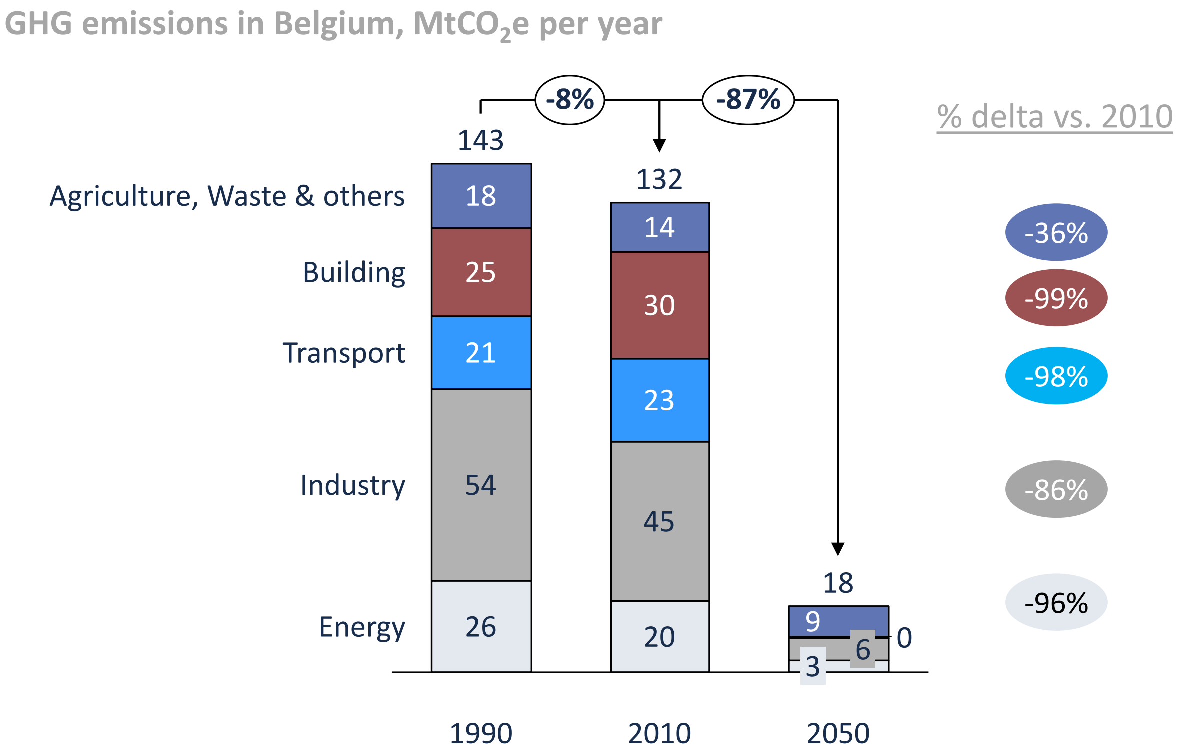


Figure 66. EU INTEGRATION, GHG Emissions, sectoral view.

Appendix 3 – Role of the Consultation Group

The study has benefited from the support of a Consultation Group. The role of the Consultation Group was to make remarks and observations on the proposed scenarios all leading to GHG emission reductions of at least 80% in Belgium in 2050 with respect to 1990, in the context of the law on the nuclear phase out. It was composed of four academic members, three representatives of the main stakeholders involved (business, labour and environmental organisations) and three representatives of the regional environmental administrations.

In practice, it was asked to the members to react on:

- the choice of the main parameters and levers to reduce emissions, as well as the levels of ambition of these levers which are the basis for building the scenarios; the interaction took place in written form
- the scenarios elaborated by the consultants; the interaction took place during a workshop organised on 18 February 2013.

The reactions and the guidance provided by the members have served as an input to the authors of the study to allow them to reinforce the coherence, relevance and usefulness of the scenarios with respect to the low carbon transition challenge.

The final responsibility for the scenario analysis lies with the authors of the study. Therefore, the analyses, the elaborated scenarios and the results of the study do not necessarily reflect the point of view of the members of the Consultation Group or of the experts consulted during the work. So, the members of the Consultation Group and the consulted experts do not necessarily endorse the analyses or the conclusions of the study.

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